Moose Creek

Fairbanks North Star Borough | Alaska

INFORMATION TO PROTECT OUR COMMUNITIES

Per- and Polyfluoroalkyl Substances (PFAS) Exposure Assessment

REPORT

National Center
for Environmental Health
Agency for Toxic Substances
and Disease Registry

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About ATSDR

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency of the U.S. Department of Health and Human Services (HHS). ATSDR works with other agencies and state, tribal and local governments to protect communities from harmful health effects related to exposure to natural and manmade hazardous substances. For more information about ATSDR, visit https://www.atsdr.cdc.gov/

Abbreviations

9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid
AFFF	aqueous film forming foam, also known as “A triple F”
AK DEC	Alaska Department of Environmental Conservation
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
DONA	4,8-dioxa-3H-perfluorononanoic acid
EA	exposure assessment
EPA	U.S. Environmental Protection Agency
EtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid
FOD	frequency of detection
FtS 4:2	fluorotelomer sulfonic acid 4:2
FtS 6:2	fluorotelomer sulfonic acid 6:2
FtS 8:2	fluorotelomer sulfonic acid 8:2
GAC	granular activated carbon
HA	health advisory
HFPO-DA (GenX)	hexafluoropropylene oxide dimer acid
LOD	limit of detection
MeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid
µg/L, or ug/L	micrograms per liter (same as parts per billion or 1,000 parts per trillion)
ng/g	nanograms per gram (same as parts per billion or micrograms per kilogram)
NHANES	National Health and Nutrition Examination Survey
N-EtFOSA	N-ethyl perfluorooctanesulfonamide
N-EtFOSE	N-ethyl perfluorooctanesulfonamidoethanol
N-MeFOSA	N-methyl perfluorooctanesulfonamide
N-MeFOSE	N-methyl perfluorooctanesulfonamidoethanol
n-PFOA	linear isomer of PFOA
n-PFOS	linear isomer of PFOS
PCL	protective concentration level
PFAS	per- and polyfluoroalkyl substances
PFBA	perfluorobutanoic acid
PFBS	perfluorobutane sulfonic acid
PFDA	perfluorodecanoic acid
PFDoA	perfluorododecanoic acid
PFDS	perfluorodecane sulfonic acid
PFDoS	perfluorododecanesulfonate
PFHpA	perfluoroheptanoic acid
PFHpS	perfluoroheptane sulfonic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexane sulfonic acid

PFNA	perfluorononanoic acid
PFNS	perfluorononane sulfonic acid
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonic acid
PFOSA	perfluorooctanesulfonamide
PFPeA	perfluoropentanoic acid
PFPeS	perfluoropentane sulfonic acid
PFTA	perfluorotetradecanoic acid
PFTrA	perfluorotridecanoic acid
PFUnA	perfluoroundecanoic acid
ppt	parts per trillion (same as 1 nanogram per liter)
Sb-PFOA	branched isomers of PFOA
Sm-PFOS	branched isomers of PFOS

Executive Summary

Background and Purpose

PFAS (or per- and polyfluoroalkyl substances) are a family of synthetic chemicals that have been used in industry and consumer products since the 1950s. There are thousands of different PFAS. This assessment discusses some of the most commonly studied PFAS, including perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), perfluoroundecanoic acid (PFUnA), and N-methyl perfluorooctanesulfonamidoacetic acid (MeFOSAA).

PFAS do not occur naturally but are widespread in the environment. They have been found in soil, water, air, and animal and plant life. Most PFAS (including PFOA, PFOS, PFHxS, and PFNA) are either very resistant to breaking down or degrade into other PFAS that do not degrade further. Major exposure routes for PFAS include drinking contaminated water and eating contaminated food, but exposure can also occur through other routes (i.e., ingestion of contaminated dust). Once PFAS enter people's bodies, some of them (including PFOA, PFOS, PFHxS, and PFNA) can remain in the body for long periods and can be measured in the blood years after exposure. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of National Health and Nutrition Examination Survey (NHANES) samples collected for the 1999-2000 survey cycle.

The Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) are conducting exposure assessments (EAs) in communities that were known to have PFAS in their drinking water and are near current or former military bases. This report shares results from the community of Moose Creek in Fairbanks North Star Borough, Alaska, near Eielson Air Force Base (the Base). When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

Possibly as early as the 1980s, the Base used aqueous film forming foam (AFFF) containing PFAS for its firefighter training. Over time, the PFAS from the AFFF entered the ground, moved into the groundwater to offsite locations, and affected nearby private wells in Moose Creek. PFAS were first detected in private wells downgradient of the Base in May 2015. To reduce levels of PFAS in drinking water, the Air Force immediately began providing bottled water to Moose Creek households served by the affected wells. The Air Force eventually implemented other mitigation efforts, including installing underground storage tanks, above-ground storage tanks, bottled water delivery services, and whole-house granulated activated carbon (GAC) filtering systems. Based on information available to ATSDR, the alternative drinking water provided by the Air Force (whether through filters, bottled water, or tanks) currently meets or is below the U.S. Environmental Protection Agency's (EPA) 2016 health advisory (HA) and state public health guidelines for PFAS in drinking water. At this time, ATSDR recommends that households continue to use the alternative sources of water provided by the Air Force. Note that a small number of households in the sampling frame refused testing for PFAS in private wells offered by the Air Force. Because of this, ATSDR is unable to definitively conclude that all drinking water exposures in the area have been mitigated; however, all known drinking water exposures have been mitigated and the Air Force has continued to take action to mitigate exposures when new data become available.

This EA assessed PFAS levels in the blood and urine of Moose Creek residents living near Eielson Air Force Base, where many private wells had PFAS levels above federal or state guidelines. Test results were compared to PFAS levels in a nationally representative sample. Tap water and indoor dust samples from a subset of households were analyzed. Note that when we write "tap water" in this report we are

referring to the drinking water source that was present in a household at the time of EA sample collection, which could be either filtered private well water or delivered water. These EA results will help participants and their communities better understand their PFAS exposure, allow ATSDR to provide recommendations to reduce exposure, and inform public health efforts related to protecting communities from sources of PFAS other than contaminated drinking water supplies.

ATSDR will use the data collected from this and other EAs to help inform future studies of PFAS exposure.

Exposure Assessment Activities

ATSDR invited all Moose Creek residents who met eligibility criteria to participate in the EA. To be eligible to participate, household residents must have (1) received their drinking water from a private well in Moose Creek for at least 1 year before December 28, 2017 (these residents have the greatest likelihood of past exposures to PFAS via their private well drinking water), (2) been greater than three years old at the time of sample collection, and (3) not been anemic or had a bleeding disorder that would prevent giving a blood sample.

Overall, 88 eligible people (79 adults and 9 children) from 48 households participated in the EA sample collection event. ATSDR performed the following tasks:

- administered exposure history questionnaires to all participants
- collected blood and urine samples from every participant
- collected tap water and dust samples from the homes of 13 randomly selected participants
- tested for 7 PFAS in blood, 14 in urine, 18 in water, and 33 in dust[1]
- measured PFHxS, PFOS, PFOA, PFNA, PFDA, and PFUnA across all media
- mailed individual biological and environmental results to participants in February 2021

This report summarizes community PFAS blood levels, measured in serum, for the group of Moose Creek participants. In this report, when we write blood levels of PFAS, we are referring to the measurement of PFAS in the serum fraction of the blood. This report also summarizes urine sample results from a subset of participants and presents results from the dust and tap water samples. Finally, the relationships between blood results and the environmental sampling data are explored. The Moose Creek blood and urine results are compared to a nationally representative sample of the US population. Specifically, ATSDR compared Moose Creek data to those collected by CDC as part of its National Health and Nutrition Examination Survey (NHANES). The NHANES survey collects blood and urine samples from a representative sample of the civilian non-institutionalized U.S. population and tests them for chemicals, including PFAS. PFAS levels reported by NHANES are also shown by age, race/ethnicity, sex, number of years living in the community, drinking water consumption patterns, and other exposure parameters.

The samples were collected and analyzed in accordance with ATSDR's *Exposure Assessment Protocol: Biological and Environmental Sampling of PFAS* (EA protocol) to ensure their quality. This EA was designed to estimate geometric mean concentrations of PFOS in blood for the sampling frame (Moose Creek households) population, with a precision goal of at least 15%. The precision is a measure of how wide the confidence interval is around the estimated geometric mean. ATSDR met this goal for PFOS,

[1] The laboratory reports branched and linear isomers of PFOA and PFOS in blood and urine. ATSDR reports on the sum of the individual isomer concentrations of PFOA and PFOS.

and precision for all PFAS measured in this EA ranged from approximately 10% to 23%. ATSDR also calculated geometric means that were adjusted to the age distribution of the sampling frame population to correct for participation bias and to provide an estimate that is more generalizable to the sampling frame community. ATSDR also calculated geometric means that were adjusted to the national age distribution for comparison with the 2015–2016 NHANES survey. Throughout this report, the term "average level" is used to refer to age-adjusted geometric means. To assess possible relationships between blood levels and various demographic and exposure variables, ATSDR used statistical models. Univariate statistics, which evaluate one variable at a time, were used as a tool to examine the data broadly and find patterns within the data. Multivariate statistics and regression modeling were used to simultaneously account for multiple variables and to control for potential confounding factors.[2]

Moose Creek Community-Wide Findings

Finding 1. Average blood levels of PFHxS and PFOS in the Moose Creek EA site participants are higher than national levels. Averages of other PFAS were not higher than the national levels or were detected too infrequently to compare to national levels.

Geometric means (i.e., averages) for PFHxS and PFOS blood levels were statistically higher ($p<0.05$) in Moose Creek participants when compared to CDC's NHANES (2015–2016) testing, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population from NHANES 2015–2016.

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Moose Creek EA participants was 7.7 times the national level. Blood PFHxS levels were above the national geometric mean for 96% of the Moose Creek EA participants and above the NHANES 95th percentile for 73% of the participants. The age-adjusted geometric mean blood PFOS level was 3.1 times the national level. Blood PFOS levels were above the national geometric mean for 86% of the Moose Creek EA participants and above the NHANES 95th percentile for 50% of the participants.

Other PFAS measured in this EA (PFOA and PFNA) were not higher than national levels. ATSDR was unable to compare the geometric mean MeFOSAA levels because MeFOSAA was detected in less than 60% of NHANES samples. PFUnA and PFDA were detected in fewer than 60% of the EA participant samples; due to the large percentage of samples below the limit of detection, geometric means were not calculated.

Finding 2. Elevated blood levels of PFHxS and PFOS may be associated with past drinking water contamination.

PFOS and PFOA were detected in Moose Creek private wells as early as 2015, though contamination likely began earlier. The Air Force did not provide ATSDR measurements of PFHxS in private drinking water wells. However, measurements taken from unfiltered water samples in this EA indicate that PFHxS is present in groundwater in Moose Creek. PFOS had statistically elevated blood levels compared to national geometric means. The maximum concentrations measured by the Air Force in private drinking

[2] A confounding variable is a factor that may distort or mask the relationship between a potential predictor and measure of exposure.

water wells in Moose Creek were 3,100 ppt for PFOS and 250 ppt for PFOA (note the maximum PFOA concentration measured in EA participant drinking water wells was 153 ppt).

Between 2015 and 2017, actions taken by the Air Force reduced PFAS levels in drinking water in the affected area below the EPA HA for PFOS and PFOA and Alaska Department of Environmental Conservation (AK DEC) Action Levels for multiple PFAS. Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have long biological half-lives (on the order of years). There were 2 years and 8 months between when the Air Force provided alternative water to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (4.7 to 35 years), which may contribute to why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

PFHxS and PFOS were highly correlated in Moose Creek residents' blood (Pearson correlation coefficient, $r = 0.88$). This means that, typically, residents who had elevated blood PFHxS levels also had elevated blood PFOS levels. This correlation suggests a common exposure source, such as the drinking water, though other sources of exposure may also have contributed to the observed blood levels.

Additional observations from the multivariate analyses support the finding that past exposure to contaminated drinking water contributed to the elevated blood levels.

- First, adults who reported mainly drinking bottled water at home on average had statistically lower PFHxS (57%) and PFOS (64%) blood levels when compared to those who reported mainly drinking private well water.
- Second, adults who reported drinking primarily from a public water system (which included water delivered by the Air Force) had statistically lower PFOS (56%) blood levels than those who reported drinking primarily private well water.
- Third, for each additional cup of water drank at home per day, blood PFHxS levels increased by 2.3%.

Finding 3. Age, sex, soil exposure, occupational exposure, breastfeeding, and childbirth were associated with some PFAS blood levels.

PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following relationships were statistically significant in multivariate analyses in the Moose Creek EA data set in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants, and the size of the effect varied by sex for PFHxS and PFOS.
- Males had statistically higher blood levels of PFHxS and PFOS than females. The difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS and PFOS levels than 30-year-old females by 196% and 272%, respectively. For 50-year-old participants, these differences were reduced to 88% for PFHxS and 95% for PFOS, respectively.

- Participants who reported coming in contact with soil three times a week or more had 92% higher blood PFOS levels than those who reported coming in contact with soil a few times per years or less.
- Adult participants who reported at least one occupational exposure in the past 20 years on average had higher PFHxS (239%), PFOS (96%), and PFOA (63%) than adult participants who reported no occupational exposures in the past 20 years.
- Females who breastfed had lower blood levels of PFOS than females who did not. Among female participants, for every one-month increase in breastfeeding duration, blood PFOS levels on average decreased by 1.5%.

Detailed analyses were not conducted for children because fewer than 10 children participated in this EA. The final report on all EA sites will include a more robust analysis of children.

Finding 4. No PFAS were detected in urine.

ATSDR analyzed 9 (10%) of the urine samples collected. No PFAS were detected in any of the samples; therefore, no geometric means were calculated. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 5. All Moose Creek drinking water samples collected during the EA in 2020 met the EPA's HA and the Alaska Department of Environmental Conservation (AK DEC) Action Levels for specific PFAS in drinking water.

This is based on 11 filtered and 8 unfiltered samples collected in 13 households during the EA. One of the unfiltered household samples exceeded the EPA HA level and AK DEC Action Level for PFOS; however, this sample was untreated private well water collected at an outdoor spigot that was not used for drinking water. ATSDR also collected water from an unfiltered, unused tap in the sampling frame and found that the PFOS concentration exceeded the EPA HA level and AK DEC Action Level.

Finding 6. Patterns and levels of dust contamination measured in participating EA households are comparable to those reported in selected U.S. studies.

Among the PFAS detected most frequently in household dust samples, N-MeFOSE and FtS 6:2 were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the small subset of participating households (n=13) were within the range of levels reported in a few published studies of other U.S. communities (with or without known PFAS contamination). Of the PFAS measured in this EA's household dust samples, PFOS and MeFOSAA were statistically correlated with the same PFAS measured in participants' blood. The final report on all EA sites will include a more robust comparison of PFAS measured in dust and blood.

Limitations

There are several limitations associated with this assessment.

- The EA participant sample may not be representative of the community. All households in the study area were invited to participate, and 15% of the households participated in the EA. Participant characteristics were different than those of the area's overall population, specifically, participants were older. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.

- The significant associations reported here between blood PFAS levels and certain demographic and exposure characteristics should be interpreted with caution as they are sometimes based on a limited number of participants.
- Measurement of blood, urine, and environmental PFAS concentrations for EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every potential confounding exposure is not possible.
- While multivariate regression models explained a moderate to large portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.48 and 0.67 in all-adult models), other factors not identified could still influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- A small number of households in the sampling frame refused testing for PFAS in private wells offered by the Air Force. Because of this, ATSDR is unable to definitively conclude that all drinking water exposures in the area have been mitigated; however, all known drinking water exposures have been mitigated and the Air Force has continued to take action to mitigate exposures when new data become available.
- This EA did not directly assess participants' tap water consumption prior to the mitigation or reduction of PFAS in drinking water from private wells.
- This EA was not designed to investigate health outcomes. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us how, where, when, or for how long a person was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.
- The dust results are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample mass.

Recommendations

This PFAS EA provides evidence that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. These PFAS are eliminated from the body over a long period of time. This allowed ATSDR to measure PFAS even though exposures through drinking water were mitigated, or lowered, years ago.

Although the exposure contribution from PFAS in private well water in Moose Creek has been mitigated, there are actions community members and other stakeholders can take to further reduce exposures to PFAS and protect public health.

Based on the PFAS drinking water test results from private wells tested by the Air Force in Moose Creek, ATSDR recommends that residents continue to use the alternative sources of water provided by the Air Force at this time.

1. What the Air Force can/should do:
    a. With permission from homeowners, test private wells in the affected area that have not been previously tested.
    b. Continue to monitor and maintain alternative drinking water systems to ensure that the water provided continues to meet all federal and state drinking water guidelines for PFAS.

2. What community members can/should do:
    a. The Air Force has taken action to reduce levels of PFAS in drinking water at homes near Eielson Air Force Base. Based on the information available to ATSDR, the alternative drinking water provided by the Air Force (whether through filters, bottled water, or tanks) currently meets all federal and state guidelines for PFAS. ATSDR recommends that community members continue to use these alternative water sources. The long-term solution is to connect your home to piped water from a source that meets all federal and state drinking water guidelines for PFAS.
    b. Residents should coordinate monitoring and maintenance of the water filtration systems with the Air Force until such time as piped water is supplied.
    c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the potential risks for infants exposed to PFAS in breast milk.
    d. When possible, eliminate or decrease potential exposure to PFAS in consumer products, such as stain-resistant products and food packaging materials. To learn more visit: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food
    e. Pay attention to advisories about food consumption, such as local fish advisories. Because of PFAS in lakes and creeks near Eielson Air Force Base, Alaska Department of Fish and Game only allows catch and release sport fishing in Polaris Lake, Bear Lake, Moose Lake, Bathing Beauty Pond, Piledriver Slough, and Moose Creek.
    f. Discuss any health concerns or symptoms with your health care provider. Share results of PFAS blood testing with your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html). Follow the advice of your health care provider and the recommendations for checkups, vaccinations, prenatal care, and health screening tests.
    g. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives—some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near-term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects.

       For the general population, blood tests for PFAS are most useful when they are part of a scientific investigation like this EA. Test results will tell you how much of each PFAS is in your blood, but it is unclear what the results mean in terms of possible health effects. In addition, blood testing for PFAS is not a routine test offered by most doctors or health departments. If you are concerned about the effect of PFAS on your health, talk to your health care provider and make them aware of ATSDR resources for clinicians. (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html).
    h. Follow the advice of your child's health care provider and the recommendations for well child checkups, vaccinations, and recommended health screening tests. Consult https://health.gov/myhealthfinder to help identify those vaccinations and tests.
    i. For additional information about environmental exposures and children's health, contact the Pediatric Environmental Health Specialty Units, a nationwide network of experts in reproductive and children's environmental health (https://www.pehsu.net/).

For More Information

If you have questions or comments or want more information on the Moose Creek EA site, call 800-CDC-INFO or email pfas@cdc.gov. For more information on the work CDC/ATSDR is doing to address PFAS exposure, visit ATSDR's PFAS website: https://www.atsdr.cdc.gov/pfas/. For other EA or PFAS-related questions, email pfas@cdc.gov.

Background and Purpose

The Centers for Disease Control and Prevention (CDC) and the Agency for Toxic Substances and Disease Registry (ATSDR) are conducting exposure assessments (EAs) in communities near current or former military bases that are known to have had per- and polyfluoroalkyl substances (PFAS) in their drinking water. One of these communities is Moose Creek in Fairbanks North Star Borough, Alaska. This report summarizes the findings of the Moose Creek EA. When all EAs are complete, ATSDR will prepare a report describing the results across all sites.

Exposure assessment (EA) participants were recruited among Moose Creek residents living near Eielson Air Force Base where many private wells had PFAS levels above state or federal guidelines. For the purposes of this report, we refer to the "Moose Creek EA" to describe the EA conducted in this area. For more information and a map of the area see the "Methods" section of the report.

The EA involved collecting responses to exposure history questionnaire responses, biological samples (blood and urine), and environmental samples (tap water and household dust). Note that when we write "tap water" in this report we are referring to the drinking water source that was present in a household at the time of EA sample collection, which could be either filtered private well water or delivered water. ATSDR collected biological samples at the Moose Creek Fire Station between August 18 and August 25, 2020. During this same time frame, ATSDR administered questionnaires over the phone and took water and dust samples in a subset of randomly chosen participant homes.

The results of the EA

- tell us the amount of PFAS in the blood of individual participants and the Moose Creek community and how these levels compare to the general U.S. population,
- tell us the amount of PFAS in the urine of individual participants and the EA community and how these levels compare to the general U.S. population,
- provide a better understanding of environmental factors that affect PFAS exposure,
- provide information that may be used to stop or reduce PFAS exposure,
- produce information that public health professionals can use to help communities affected by PFAS, and
- inform future studies looking at the effect of PFAS exposure on human health.

The EA does not look at what types of health problems are associated with exposure and is not meant to determine if PFAS levels in blood or urine are risk factors for illness now or later in life. Additionally, the EA does not tell us exactly how or where people were exposed or when or how long PFAS exposure lasted.

ATSDR's *Exposure Assessment Protocol: Biological and Environmental Sampling of PFAS,* termed the PFAS EA Protocol [ATSDR 2019a], provides additional background, describes the criteria for selecting communities for the EAs, and highlights the procedures ATSDR used in conducting the EAs.

What Are PFAS?

Human exposure to PFAS is a growing environmental health concern. PFAS are synthetic chemicals used in many industries and consumer products since the 1950s. They have been used in nonstick cookware; water-repellent clothing; stain-resistant fabrics and carpets; cosmetics; firefighting foams; and products

that resist grease, water, and oil [Buck et al. 2011; Gluge et al. 2020; Wang et al. 2017]. Exposure to PFAS has been associated with increased cholesterol, decreased vaccine response in children, changes in liver enzymes, small decreases in infant birth weights, increased risk of high blood pressure or pre-eclampsia in pregnant women, and increased risk of kidney and testicular cancer [ATSDR 2021].

There are thousands of different PFAS. This assessment discusses some of the most commonly studied PFAS, which include perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexane sulfonic acid (PFHxS), perfluorononanoic acid (PFNA), perfluorodecanoic acid (PFDA), and perfluoroundecanoic acid (PFUnA). The manufacture and import of PFOA, precursor chemicals that can break down to PFOA, and related higher homologue chemicals, have been mostly phased out in the United States. However, existing stocks of PFOA might still be used, and there might be PFOA in some imported articles. PFOS manufacture in the United States has not been reported to the EPA since 2002, however, there are some limited ongoing uses of PFOS. These PFAS with long perfluoroalkyl chains are no longer produced in the United States because of concerns over their high persistence, tendency to bioaccumulate, and potential risks to human health and the environment. Other countries may still manufacture and use them, but U.S. manufacturers have replaced these compounds with shorter chained PFAS, or chemicals with alternative chemistries, such as GenX (HFPO-DA), which typically have shorter biological half-lives. Some of the PFAS discussed in this report, such as N-methyl perfluorooctanesulfonamidoacetic acid (MeFOSAA), are considered precursors that can degrade in the environment or in people to other PFAS [ATSDR 2021; Wang et al. 2017].

PFAS do not occur naturally but are widespread in the environment. PFAS can be released into the environment during their production, use, or disposal. PFAS have been found in soil, sediment, water, animal and plant life, and air. Most PFAS (including PFOA, PFOS, PFHxS, and PFNA) are either very resistant to breaking down or degrade into other PFAS that do not degrade further. Certain PFAS will therefore remain in the environment indefinitely. Most people in the United States have been exposed to PFAS. At least one PFAS was detected in more than 99% of NHANES samples (1999-2000 survey cycle) [Calafat et al. 2007a]. Exposure can occur via contaminated drinking water for which ingestion is believed to be the primary exposure route. Studies have shown that showering, bathing, and swimming in water containing PFAS at levels seen in Moose Creek are not expected to be an important contributor to PFAS exposure relative to the contribution from drinking water [Sunderland 2019].

ATSDR's PFAS EAs focused on communities with known exposures via contaminated drinking water. However, residents may have had additional exposures to PFAS, such as the following [Sunderland 2019]:

- eating food packaged in materials containing PFAS (e.g., popcorn bags, fast food containers, pizza boxes)
- eating fish or shellfish caught in PFAS-contaminated waters
- using consumer products such as stain-resistant carpeting and water-repellent clothing
- eating garden vegetables grown with PFAS-contaminated water or soil
- accidentally swallowing PFAS-contaminated soil
- drinking infant formula mixed with PFAS-contaminated water
- consuming breastmilk from women exposed to PFAS
- gestational exposure to PFAS
- working in industries that manufacture, process, or use products containing PFAS

- background exposure to PFAS due to their ubiquitous nature

ATSDR asked study participants about these types of potential exposures to evaluate whether these exposures might influence PFAS levels in the EA communities.

After PFAS enter the human body, some PFAS can remain there for a long time. Some studies estimate the half-life of PFHxS is between 4.7 and 35 years [ATSDR 2021]. Half-life estimates range from 3.3 to 27 years for PFOS and from 2.1 to 10.1 years for PFOA [ATSDR 2021].

The body of science about PFAS exposure and health effects is growing rapidly. Some, but not all, scientific studies have shown that exposure to certain PFAS may be linked to harmful health effects. While this EA does not examine specific health outcomes associated with PFAS exposure, EA findings might help inform future studies on how PFAS exposure affects human health.

Why Moose Creek?

Moose Creek was one of several sites located near military installations with identified PFAS drinking water contamination from use of products such as aqueous film forming foam (AFFF). When selecting EA sites, ATSDR considered the extent of PFOA and PFOS contamination in drinking water supplies, the duration over which exposure may have occurred, and the number of potentially affected residents.[3]

PFAS and precursors that degrade to other compounds measured in this EA were used in historical AFFF formulations. Two types of PFAS-containing AFFF were manufactured before 2016 [ITRC 2020]. Both formulations contained PFAS or PFAS precursors, the use of which resulted in the release of PFOS, PFHxS, PFOA, and PFHxA into the environment. Possibly as early as the 1980s, Eielson Air Force Base (the Base) used AFFF containing PFAS for its firefighter training (AFIMSC 2018). Over time, the PFAS from the AFFF moved off site in groundwater and contaminated nearby private wells.

When PFAS first entered private wells in Moose Creek is not known. These substances were first detected in private wells near the Base in May 2015, through testing conducted by the Air Force. In June 2015, the first results indicated that PFOS was detected in every well sampled. Further, in more than 90 percent of these samples, PFOS levels exceeded the provisional U.S. Environmental Protection Agency's (EPA's) HA for PFOS levels in drinking water at the time (200 ppt). In May 2016, EPA lowered the provisional health advisory to the current level of 70 ppt for PFOA+PFOS. Alaska Department of Environmental Conservation's (AK DEC's) current action level for groundwater and drinking water aligns with EPA's HA level for PFOA+PFOS. ATSDR reviewed drinking water well sampling data provided by the Air Force. The highest sampling result from a private drinking water well was 3,240 parts per trillion (ppt) for the sum of PFOA and PFOS. Across samples, the maximum PFOS concentration detected in a private drinking water well was 3,100 ppt, and the maximum PFOA concentration was 250 ppt. These two compounds were the only PFAS reported by the Air Force in its residential drinking water well sampling.

The Air Force immediately provided bottled water to households with PFAS levels above EPA's HA and AK DEC Action Levels. To reduce concentrations of PFOA and PFOS in drinking water, the Air Force installed whole-house granular activated carbon (GAC) treatment systems in affected homes or installed underground and above-ground storage tanks at affected homes. Water from an alternate source was

[3] PFHxS data were not available for all sites evaluated so were not considered in the site selection process even though water contaminated by AFFF often has higher concentrations of PFHxS than PFOA or PFOS.

then delivered to the storage tanks. The last time the Air Force measured PFAS concentrations in a Moose Creek private well above EPA's HA or AK DEC Action Levels, prior to these mitigation measures, was in December 2017.

The information available to ATSDR indicates that in 2020 the alternative drinking water provided by the Air Force (whether through filters, bottled water, or tanks) met or were below the EPA's HA and the AK DEC's Action Levels for PFAS in drinking water. The long-term solution is to connect affected households to piped water from a source that meets all federal and state drinking water guidelines for PFAS. No off-base public water systems were affected in this area.

Methods

ATSDR's PFAS EA protocol [ATSDR 2019a] details the approaches used to recruit participants, collect samples, administer exposure history questionnaires, and evaluate data. This section briefly describes how those methods were applied to the Moose Creek EA.

Sampling Frame

This EA targeted a specific geographic area, called the sampling frame or sampling area. The sampling frame for this EA was the community of Moose Creek, Alaska. This is the part of Fairbanks North Star Borough near Eielson Air Force Base where many private wells had PFAS levels above state or federal guidelines (see Figure 1). Based on a review of Moose Creek land parcel data, ATSDR identified 317 households in the sampling frame. These households formed the sampling frame from which households were invited to participate.

Participant Eligibility

Moose Creek residents who met the following criteria were eligible to participate in the EA:

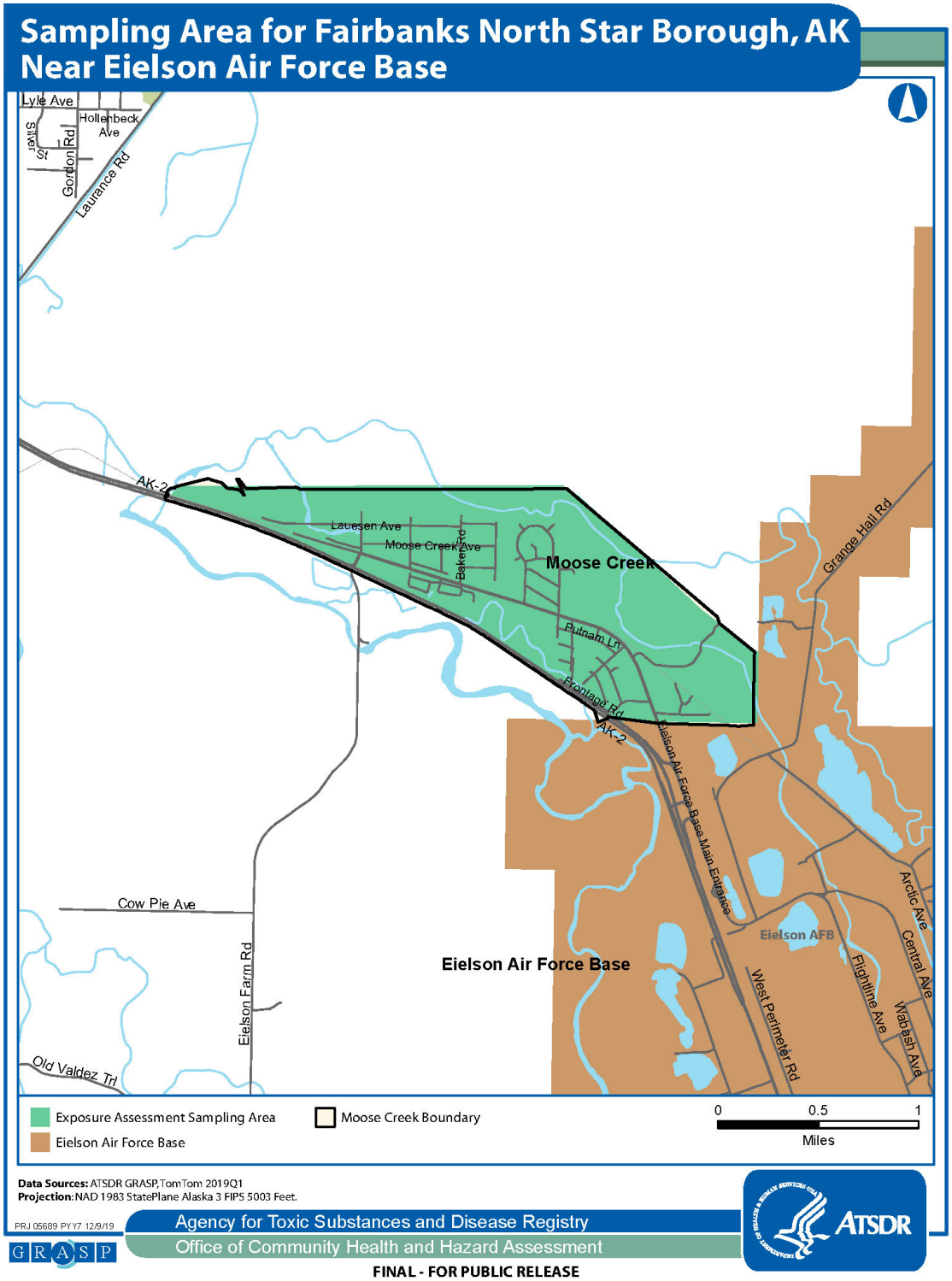
- Lived within the sampling frame (i.e., the entire Moose Creek community) for at least one year before December 28, 2017, which is the last time the Air Force measured PFAS drinking water concentrations in a private well above EPA's HA or AK DEC's Action Levels.
- Were at least 3 years old at the time of recruitment. This age criterion was used because national reference values are not available children under the age of three.
- Did not have bleeding disorders and were not anemic, unless they confirmed with their doctor the ability to safely provide a blood sample.

People potentially exposed to PFAS occupationally, such as firefighters, active-duty military, and veterans were able to participate if they met the three eligibility criteria. Participants did not receive incentives and paid no costs to participate.

Participant Recruitment

ATSDR invited all 317 households identified in the sampling frame to participate. All households were chosen to attempt to achieve the protocol recruitment target of 395 participants. ATSDR mailed invitations to 317 households. All members of each household who met eligibility criteria were invited to participate.

Figure 1. Sampling frame for the Moose Creek Exposure Assessment (Fairbanks North Star Borough)



Recruitment was done during an ATSDR informational meeting held in Moose Creek and through mailings, phone calls, and door-to-door recruitment. Every household received an in-person visit. Subsequently, every household for which ATSDR had a phone number received up to three recruitment calls. In each attempt, ATSDR called all working phone numbers (cellphone and landline) associated with a household. For calls that went to voicemail, ATSDR staff left messages encouraging residents to call back to schedule appointments.

After recruitment, 93 residents from 46 households scheduled appointments for biological sampling and questionnaire completion. In total, 48 households participated in the Moose Creek EA because of several walk-in participants.

ATSDR attempted to recruit 10 of the participating households for environmental sampling. ATSDR invited 30 households in two waves of recruitment. In total, ATSDR scheduled 13 environmental sampling appointments.

Data Collection and Analysis

The Moose Creek EA involved collection of three types of data: questionnaires, biological samples (blood and urine), and environmental samples (tap water and household dust). The ATSDR project team collected biological samples at the Moose Creek Fire Station between August 18 and August 25, 2020. During this same time frame, ATSDR administered questionnaires over the phone and collected environmental samples in a subset of randomly chosen participant homes. One additional participant who met the eligibility criteria provided a biological sample to ATSDR on September 23, 2020, at its PFAS sampling event in Colorado. ATSDR administered a phone questionnaire to this participant as well. All data met the stringent quality control requirements for sample collection and analysis.

Before any data collection, ATSDR obtained written consent from the participants. The purpose of the consent process was to ensure participants were fully aware of the purpose of the EA, sample collection procedures, benefits and risks of participating, and privacy protections. Copies of consent forms are included in the PFAS EA Protocol.

ATSDR project staff handled all data collected in accordance with the *Standard Operating Procedures of PFAS Exposure Assessment Data Management* [ATSDR 2019b]. These procedures have very strict requirements for handling any personally identifiable information. ATSDR project staff protected this information to the extent required by federal and Alaska law. All signed consent forms were mailed to and are securely archived at ATSDR headquarters. Participant responses to phone questionnaires were logged directly into ATSDR's secure data network. All information provided by participants was kept confidential, and no personally identifiable information appears in any of ATSDR's public reports for this site.

Table 1, at the end of this section, provides more details on the number of participants enrolled and the final number of samples collected during this EA. Table 2 lists the PFAS measured in the EA's biological and environmental samples.

Biological Sampling and Questionnaire Administration

ATSDR administered exposure history questionnaires to 89 EA participants: 79 for adults 18 and older, and 10 for children between the ages of 3 and 17. ATSDR used one questionnaire for adults and another for children. Both addressed topics relevant to PFAS exposure, such as residential and work histories, drinking water habits, and use of PFAS-containing consumer products.

A phlebotomist collected blood samples from all 89 participants. ATSDR processed the blood samples in the field, aliquoting the serum portion of the blood.

After the sampling was complete and upon further review of each participant's residential history, ATSDR determined that one participant had not lived in the sampling frame for at least one full year before December 28, 2017, and therefore was not eligible for the study. Questionnaire and biological data for this participant were excluded from the data evaluation, but ATSDR sent this participant their individual results. This means that a total of 88 blood samples (79 adults and 9 children) were considered in the community exposure summary. These samples were collected from participants residing in 48 unique households. This represents a household participation rate of 15% (i.e., 15% of the 317 recruited households had at least one person participate in the EA).

Urine samples were collected from 86 participants (76 adults and 10 children). Per the EA protocol, 10% of the urine samples were randomly selected for initial analysis. ATSDR randomly selected 9 samples for analysis. These samples were collected from participants (8 adults and 1 child) who resided in 9 unique households.

CDC's National Center for Environmental Health laboratory analyzed the serum portion of blood and urine samples for the suite of PFAS measured in the 2015–2016 National Health and Nutrition Examination Survey (NHANES) [CDC 2019]. As part of NHANES, CDC takes biological samples and tests them for chemicals, including PFAS, from a representative sample of 5,000 people across the country during each two-year cycle. All laboratory analyses followed established procedures for quality assurance and control according to the Center's methodology.

During the consent process, participants were given the option to allow ATSDR to store biological samples for potential future PFAS analysis. Blood and urine samples from participants who provided this consent are being stored frozen at CDC for potential future analysis.

Environmental Sampling

ATSDR collected tap water and dust samples from all 13 households that had scheduled appointments. At each participating household, ATSDR collected a drinking water sample from the kitchen tap. If point-of-use filtration was in place, ATSDR project staff attempted to collect a sample before and after filtration. Tap water samples were collected and analyzed in accordance with EPA's Method 537.1: Determination of Selected Per- and Polyfluorinated Alkyl Substances in Drinking Water by Solid Phase Extraction and Liquid Chromatography/Tandem Mass Spectrometry [Shoemaker and Tettenhorst 2018].

Project staff also collected a composite dust sample from the floor at a minimum of three locations inside each selected home: the primary living space as identified by the homeowner (e.g., living room, family room, television room), the kitchen, and the bedroom in which participants reported spending the most time. Dust collection was intended to generate more information about the contribution of non-drinking-water exposures to overall PFAS exposure. Participants were instructed not to vacuum carpeting or sweep floors for five days prior to the scheduled visit. Adapting methods described in Scher et al. [2018], ATSDR collected dust samples using a high-volume air sampler connected to an open-faced 37 millimeter filter cassette with an 0.8 micron filter. A wooden 2 square foot (ft^2) sampling template was used to mark off each sampling area. ATSDR project staff attempted to collect at least 1 gram of dust in the open-faced cassettes from each home by vacuuming the same 2 ft^2 surface at least four times with the cassette (vertically, horizontally, and in circles). Samples were taken preferentially from mats, carpets, and area rugs. Household dust samples were analyzed in accordance with SGS AXYS Method MLA-110 (revision 01, version 06), *Analytical Procedure for the Analysis of Per- and*

Polyfluoroalkyl Substances (PFAS) in Aqueous Samples, Solids and Solvent Extracts by LC-MS/MS [SGS AXYS 2019].

The environmental samples collected during the EA were consumed in the analytical process and are not available for potential future analysis.

Table 1. Summary of recruitment and data collection efforts

Recruitment	
Households invited to participate by mail	317
Households reached by mail	175
Households reached by phone	117
Household door-to-door visits	317
Biological sampling:	
Individuals enrolled	93
Households enrolled	46
Environmental sampling:	
Wave 1 households invited	15
Wave 2 households invited	15
Households enrolled	13
Data Collection	
Completed questionnaires	*89*
Adults	*79*
Children	*10*
Blood samples	
Included in community statistics (48 households)	88
Adults	*79*
Children	*9*
Urine samples	
Collected	86
Adults	76
Children	10
Included in community statistics (9 households)	9
Adults	*8*
Children	*1*
Dust samples collected and analyzed (one composite sample per household)	13
Tap water samples collected and analyzed (13 households)	19
Filtered well samples	11
Unfiltered well samples	8

Table 2. List of PFAS measured for in blood, urine, tap water, and dust

PFAS Abbreviation	PFAS Chemical Name	Measured in Blood?	Measured in Urine?	Measured in Water?	Measured in Dust?
PFBS	perfluorobutane sulfonic acid		✓	✓	✓
PFPeS	perfluoropentane sulfonic acid				✓
PFHxS	perfluorohexane sulfonic acid	✓	✓	✓	✓
PFHpS	perfluoroheptane sulfonic acid				✓
PFOS	perfluorooctane sulfonic acid	✓	✓	✓	✓
n-PFOS	sodium perfluoro-1-octanesulfonate	✓	✓		
Sm-PFOS	mixture of sodium perfluoro-5-methylheptane sulfonate isomers	✓	✓		
PFNS	perfluorononane sulfonic acid				✓
PFDS	perfluorodecane sulfonic acid				✓
PFDoS	perfluorododecanesulfonate				✓
PFBA	perfluorobutanoic acid		✓		✓
PFPeA	perfluoropentanoic acid		✓		✓
PFHxA	perfluorohexanoic acid		✓	✓	✓
PFHpA	perfluoroheptanoic acid		✓	✓	✓
PFOA	perfluorooctanoic acid	✓	✓	✓	✓
n-PFOA	ammonium perfluorooctanoate	✓	✓		
Sb-PFOA	mixture of perfluoro-5-methylheptanoic acid isomers	✓	✓		
PFNA	perfluorononanoic acid	✓	✓	✓	✓
PFDA	perfluorodecanoic acid	✓	✓	✓	✓
PFUnA	perfluoroundecanoic acid	✓	✓	✓	✓
PFDoA	perfluorododecanoic acid			✓	✓
PFTrA	perfluorotridecanoic acid			✓	✓
PFTA	perfluorotetradecanoic acid			✓	✓
PFOSA	perfluorooctanesulfonamide				✓
N-MeFOSA	N-methylperfluorooctanesulfonamide				✓
MeFOSAA	N-methyl perfluorooctanesulfonamidoacetic acid	✓		✓	✓
N-MeFOSE	N-methylperfluorooctanesulfonamidoethanol				✓
N-EtFOSA	N-ethylperfluorooctanesulfonamide				✓
N-EtFOSAA	N-ethyl perfluorooctanesulfonamidoacetic acid			✓	✓
N-EtFOSE	N-ethylperfluorooctanesulfonamidoethanol				✓
FtS 4:2	fluorotelomer sulfonic acid 4:2				✓
FtS 6:2	fluorotelomer sulfonic acid 6:2				✓
FtS 8:2	fluorotelomer sulfonic acid 8:2				✓
HFPO-DA (GenX)	hexafluoropropylene oxide dimer acid		✓	✓	✓
DONA	4,8-dioxa-3H-perfluorononanoic acid		✓	✓	✓
9Cl-PF3ONS	9-chlorohexadecafluoro-3-oxanone-1-sulfonic acid		✓	✓	✓
11Cl-PF3OUdS	11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid			✓	✓

Statistical Analysis

The EA Protocol describes the statistical methods used. Briefly, the data objectives of this EA were to (1) estimate geometric mean concentrations of PFAS in the sampling frame population (with a precision target of at least 15% and a 5% level of significance for PFOS), (2) compare community level data to national levels, and (3) explore relationships between questionnaire data and measured biological and environmental data.

ATSDR processed the PFAS sampling results in two ways before performing statistical analyses:

- First, ATSDR substituted all non-detect observations with a value equal to the limit of detection (LOD) divided by the square root of 2. (A non-detect result means the sample did not contain enough PFAS to be reliably measured by this project's highly sensitive laboratory methods.) This substitution method is consistent with that applied in CDC's NHANES. Note that Appendix B provides the results of a sensitivity analysis exploring alternate substitution approaches.
- Second, ATSDR calculated the total PFOA and total PFOS concentrations measured in each blood and urine sample. The laboratory reports two different measurements for PFOA and PFOS. For PFOA, the laboratory reports the amount of branched PFOA (Sb-PFOA) measured in the sample separate from the amount of linear PFOA (n-PFOA) in the same sample. ATSDR summed these values and performed statistical analyses using total PFOA results. Similarly, ATSDR calculated total PFOS by summing the linear PFOS (n-PFOS) and branched PFOS (Sm-PFOS) concentrations. These same summation methods are applied to NHANES data.

For blood and urine, ATSDR first calculated summary statistics for each PFAS (i.e., frequency of detection, maximum detected concentration, geometric mean, 95% confidence intervals around the geometric mean, and 25th, 50th [median], 75th, 90th, and 95th percentiles). The protocol specified that geometric means would be calculated if >=60% of samples had detections. Geometric means were calculated as the measures of central tendency because of the lognormal distribution

Statistical Terms

Geometric mean: The geometric mean is a type of average and provides an estimate of the central point of a set of numbers. It is often used for environmental data that exhibit a skewed distribution (e.g., a data set with several values that are much higher than the rest of the results). The geometric mean is less influenced by high values than an arithmetic mean.

Percentiles (25th, 50th, 75th, 90th, 95th): A percentile provides additional information about the distribution of a data set and represents the value below which a certain percentage of the data fall. For example, a 95th percentile of 25 micrograms per liter (µg/L) indicates that 95% of results fall below this concentration.

Confidence intervals: A confidence interval provides information about the reliability of a statistic. In this EA, ATSDR estimated geometric means for the PFAS blood levels measured among study participants. The 95% confidence interval around the geometric mean represents the range within which the true population mean is expected to lie. More specifically, if we hypothetically repeated the study 100 times, 95 times out of 100 the mean of the sampling frame population would fall within this range.

Precision: Precision provides information on the reproducibility of a study and is associated with sample size. The larger the sample size the higher the precision. In the context of this EA, precision was estimated based on the width of confidence intervals around the geometric mean. A wide confidence interval indicates low precision while a narrow confidence interval suggests high precision.

of blood and urine measurements. Note that many of the statistics could not be calculated for urine due to the low detection frequency.

One of the objectives of this EA was to estimate community-level exposures. ATSDR evaluated demographic differences between the Moose Creek EA participants and all residents in the sampling frame. This was done for age, race, and ethnicity using a two-sample test for equality of proportions. To correct for participation bias, ATSDR also calculated geometric means adjusted to the age distribution of the sampling frame population using 2010 Census block data.

ATSDR compared community-level statistics for PFAS in blood to national PFAS data reported by CDC in the 2015–2016 NHANES (i.e., for the EA sample population 12 years of age and older). To control for differences in the age distribution, the EA geometric means were adjusted to the age distribution of the U.S. population during NHANES 2015–2016. Note that NHANES 2017-2018 data were not available at the time this report was originally drafted. For urine, ATSDR compared community-level data to national-level data from the 2013–2014 NHANES compiled by Calafat et al. [2019], the only nationally representative data available for PFAS in urine. ATSDR relied on two sample t-tests for these comparisons, using a p-value of less than 0.05 to identify statistically significant differences.

A **p-value** helps determine the significance of the results of a statistical test, such as the difference between two means. The lower the p-value the more likely the observed difference is not due chance alone. In this report, a p-value of less than 0.05 ($p<0.05$) is described as *statistically significant*.

ATSDR then used information gathered in the exposure questionnaire to understand and quantify how demographic data and other exposure characteristics relate to PFAS measurements in blood. For this, ATSDR relied on self-reported information, such as age, race/ethnicity, sex, length of residency in the sampling frame, tap water and food consumption patterns, and work/school history. All numerical responses were treated as continuous variables. In some cases, categorical variables were collapsed when there were too few responses (<10) in a given category. In order to explore sex-specific associations (e.g., women having biological children [yes/no], having breastfed children [yes/no], duration of breastfeeding), ATSDR also evaluated multivariate models for males and females only. Univariate and multivariate models for children were not evaluated because fewer than 10 children participated in this EA. For all univariate and multivariate analyses, ATSDR modeled log transformed (logarithm base 10 or $\log_{10}$) blood PFAS concentrations.

ATSDR did not conduct detailed statistical analyses for urine data because of low frequencies of detection. ATSDR analyzed a subset of urine samples and found no PFAS in any of the samples. The protocol specified that all urine samples would be analyzed if the geometric mean calculated for any site exceeded the 95th percentile from NHANES. The protocol specified that geometric means would be calculated if >=60% of samples had detections, and the rest of the samples would be analyzed if the calculated geometric mean exceeded the NHANES 95th percentile. Since no PFAS were detected, no geometric means were calculated for any PFAS in urine, and ATSDR did not analyze the remainder of the urine samples.

For tap water data, ATSDR compared PFAS levels measured with filtration, without filtration, and in delivered water to EPA's HA value (70 ppt for the sum of PFOA and PFOS) for PFAS in drinking water and AK DEC's Action Level for groundwater and drinking water (also 70 ppt for the sum of PFOA and PFOS). For dust, ATSDR calculated summary statistics and compared results to those in selected peer-reviewed

literature. ATSDR also evaluated correlations between PFAS levels measured in household dust and blood collected from participants residing in homes where dust samples were collected.

ATSDR conducted all statistical analyses in SAS (release 9.4, SAS Institute, Cary, NC) using complex survey procedures (e.g., SURVEYMEANS, SURVEYREG). To do this, ATSDR assigned household IDs to all participants and calculated summary statistics while accounting for clustering at the household level. For blood results across all EA participants, intra-cluster correlation coefficients ranged from 0.20 to 0.58, suggesting weak to moderate correlation of PFAS blood levels within a household, depending on the PFAS. Appendix B provides more information on clustering, as well as further details on the statistical methods used for this EA and how results from this EA compared to the assumptions used to estimate the target sample size of 395 participants.

Results

This section summarizes EA findings. It first profiles the Moose Creek EA participants and compares their demographics to the entire sampling frame, then reviews the blood, urine, tap water, and household dust measurements that ATSDR collected. Those reviews use exposure history questionnaire data to provide further context on the measurements. (The next section, "Discussion," further evaluates the observed trends using insights from the broader scientific literature on PFAS drinking water exposures.)

Most analyses in this section reflect the entire Moose Creek EA participant population, but some pertain to subsets of that population. This is because separate exposure history questionnaires were administered to adults and children and because some questions on the adult questionnaire only applied to females. Geometric means, 95% confidence intervals, and other statistical associations are not presented for children because fewer than 10 children participated in this EA.

Profile of Moose Creek EA Participants

EA participants responded to exposure history questions and reported information on many characteristics, such as their age, sex, race/ethnicity, residential and occupational history, and drinking water consumption. Table 3 summarizes this information for questions with enough responses in different categories to perform statistical analysis. See section "PFAS Blood Levels and Other Factors" for information about questions without enough responses for a meaningful statistical comparison.

The average age of EA participants was 51.0 years, and 86% of the participants identified themselves as White, non-Hispanic. Of EA participants, 45% identified as female, 55% identified as male, and 90% were adults, aged 18 years or older. The age cutoff is important because adults were administered a different exposure history questionnaire with more detailed questions. Among the adult participants, 20% reported living in their current homes for less than 10 years.

Adults were also asked about their current primary source of drinking water: 41% said delivered water (which ATSDR coded as "public water system" for purposes of the analyses), 38% said private well (most of which would have been treated with a GAC filtration system), and 22% said bottled water. Adults reported drinking an average of 9.1 8-ounce cups of water a day at home, and 58% said they currently use some type of filtering or treatment device for their drinking water. Examples include filters on refrigerators, pitchers, and faucets; whole-house carbon filtration systems; and reverse osmosis treatment systems. The questionnaire asked adults for their occupational histories over the past 20 years; 29% reported holding one or more jobs with potential PFAS exposures (e.g., firefighting, military, aviation).

Table 3. Characteristics of Moose Creek EA participants

Characteristics	Count of EA Participants (n)	Percent of EA Participants* (%)
Adults and children combined		
Age (years)	(mean = 51.0)	
<18	9	10
18 to <50	22	25
50+	57	65
Sex		
Male	48	55
Female	40	45
Race and ethnicity†		
White, non-Hispanic	76	86
non-White or Hispanic	12	14
Adults only		
Years lived at current address	(mean = 19.0)	
<10	16	20
10 to <20	33	42
20 to <30	13	16
30+	17	22
Current primary drinking water source**		
Public water system	32	41
Private well	30	38
Bottled water	17	22
Average tap water consumption while living at current home (8-ounce cups per day)	(mean = 9.1)	
0	8	10
>0 to <2	6	8
2 to <4	11	14
4 to <6	8	10
6 to <8	9	11
8+	37	47
Current use of treatment or filtration device		
One or more filter/treatment device(s)	46	58
None	33	42
Occupational exposures to PFAS in the past 20 Years		
One or more occupational exposure(s)	23	29
None	56	71

* The sums of percentages for different fields in this table do not always add up to 100%, because of rounding.

** Many participants reported that their current primary drinking water source was delivered water or water from a tank at their homes. These responses were coded as "public water system" for this EA.

† ATSDR collapsed categories for race and ethnicity for all analyses because of the few responses across categories.

Comparison of Moose Creek EA Participants' Demographics to Sampling Frame Demographics

This EA was designed to estimate PFAS levels in blood that were generalizable to the sampling frame as a whole (i.e., Moose Creek households in the affected area shown in Figure 1). The recruitment method used for this EA ensures the absence of selection bias—that is, everyone in the sampling frame was invited to participate and therefore had an equal chance of doing so. However, ATSDR also explored the potential for participation bias—that is, substantive differences between those who chose to participate and those who did not.

ATSDR used 2010 Census data (Table 4) [USCB 2010] to compare the EA participants' demographic profile with the profile of all residents in the sampling frame. The comparison revealed the following:

- **Age distribution.** The EA participants included a higher proportion of older adults (age 50+ years) and a lower proportion of younger adults (18–50 years) than the sampling frame population (Table 4). Specifically, 65% of the EA participants reported being 50 or older, but 24% of the sampling frame population falls in this age range. (ATSDR chose 50 years as a cutoff for older and younger adults based on the median age of menopause in the United States, which may affect exposure profiles.) Similarly, 25% of the EA participants reported being 18–50, but 51% of the sampling frame population falls in that age range.
- **Race/ethnicity.** Among the race/ethnicity characteristics, the percent of residents who identify as White did not show a significant difference between the EA participants and the sampling frame population (Table 4). For this comparison, combined race and ethnicity were not available at the block level from the Census. Therefore, only the race category of White was compared because of the small number of respondents in other categories.

The effect of age on blood levels and its implications on community statistics is further explored throughout this report. Refer to the "Discussion" section for ATSDR's assessment of how these demographic differences influence data interpretations.

Table 4. Demographic comparison of EA participants and the sampling frame population

Demographics	Number of Participants (n)*	Percent of Participants (%)	Sampling Frame Distribution (%)†	p-Value‡
Age Group (years)				
<18	9	—	25.7	—
18–50	22	25.0	50.5	<0.001
50+	57	64.8	23.8	<0.001
Race				
White	77	87.5	78.1	0.055
Black or African American	<10	—	5.1	—
Am. Indian & AK Native	<10	—	5.1	—
Asian	<10	—	3.0	—
Nat. Hawaiian/Pacific Islander	<10	—	0.68	—
Ethnicity				
Hispanic or Latino (of any race)	<10	—	4.7	—

* Counts may not sum to total because participants may have refused to answer questions. Counts are not shown for categories with fewer than 10 participants.

† Sampling frame data are based on the 2010 U.S. Census. Demographic characteristics of the sampling frame may have changed between 2010 and 2020, the time of this EA.

‡ Two-sample test for equality of proportions with continuity correction comparing EA and 2010 Census data. A p-value of less than 0.05 indicates a statistically significant difference between EA participants and all residents in the sampling frame.

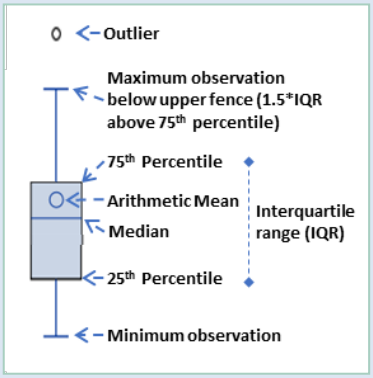
PFAS in Blood

This section summarizes PFAS levels that ATSDR measured from the 88 blood samples provided by eligible participants. Results are summarized in tables and 'box and whisker' plots (see text box).

Unadjusted Community Statistics for PFAS in Blood

ATSDR first calculated the mean levels of PFAS without accounting for the possible effect of age. Table 5 summarizes results for the seven PFAS measured in Moose Creek EA participants' blood for all ages. Five of the seven PFAS—PFHxS, PFOS, PFOA, PFNA, and MeFOSAA—were detected in more than 70% of the blood samples. ATSDR's statistical analyses throughout this section focus on these five chemicals, and Figure 2 shows the distributions of the individual measurements on a $\log_{10}$ scale. The $\log_{10}$ scale allows for more easily visualizing the wide range of serum concentrations as it uses equal spacing for each factor of 10 increase. The PFAS found at highest levels were PFOS (geometric mean = 18.3 micrograms per liter (µg/L)), PFHxS (11.7 µg/L), and PFOA (2.12 µg/L).

How to read a box and whisker plot:
A box and whisker plot illustrates a summary of the data using different statistical measures. See the image below for how to interpret the figures throughout this report.



Two PFAS—PFDA and PFUnA—were detected in fewer than 60% of the samples. Low frequency of detection for PFUnA is consistent with NHANES data. Detailed statistics are not included for these chemicals, and concentration percentiles (25^{th}, 50^{th}, 75^{th}, 90^{th}, 95^{th}) are shown only for measurements above the LOD.

The precision of geometric mean estimates for this EA for all PFAS ranged from 10% to 23% depending on the PFAS (Appendix B, Table B2). Except for PFHxS and PFOA, these values are all below the desired precision of 15% used to determine the target sample size for this EA. The collected data met the precision target specified in the EA protocol.

Table 5. Community statistics for PFAS in blood in micrograms per liter

PFAS	FOD (%)	Max	Geometric Mean	95% CI for Geometric Mean	Percentiles				
					25th	50th (Median)	75th	90th	95th
PFHxS	97.7	184.0	11.7	7.66-17.7	4.10	16.8	28.6	65.2	115
PFOS	NA*	408.1	18.3	13.2-25.5	6.80	18.2	43.0	111	146
PFOA	NA*	13.1	2.12	1.78-2.52	1.27	1.84	3.07	5.77	8.73
PFNA	94.3	3.3	0.321	0.277-0.371	0.192	0.288	0.413	0.607	0.780
PFDA	52.3	0.7	NA‡	0.121-0.148	NA†	NA†	NA†	0.237	0.330
PFUnA	31.8	0.8	NA‡	NA‡	NA†	NA†	NA†	0.153	0.220
MeFOSAA	70.5	1.2	0.137	0.113-0.166	NA†	NA†	0.169	0.380	0.580

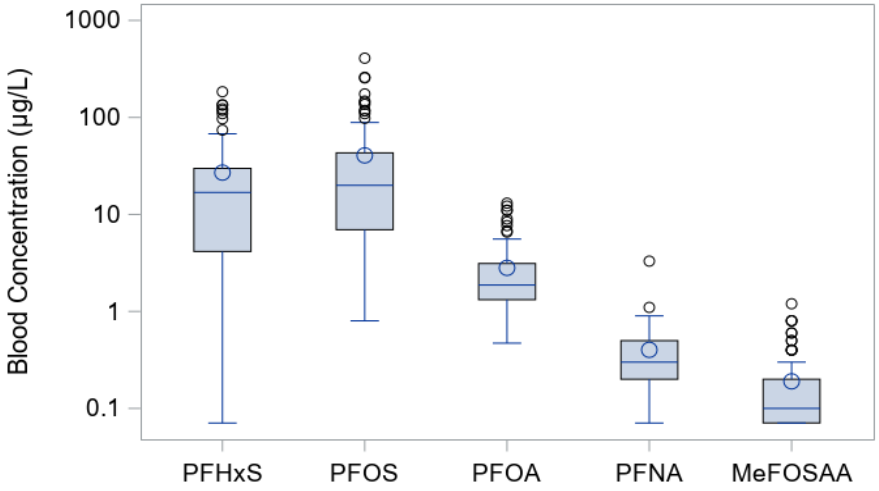
FOD = frequency of detection, CI = confidence interval, NA = not applicable. Results are based on 88 blood samples.

* PFOA and PFOS are calculated sums of branched and linear subsets and are not measured directly. Linear PFOA was detected in 100.0% of samples with a geometric mean of 2.03 micrograms per liter (µg/L); branched PFOA was detected in 0.0% of samples. Linear PFOS was detected in 100.0% of samples with a geometric mean of 12.0 µg/L; branched PFOS was detected in 100.0% of samples, with a geometric mean of 6.07 µg/L.

† Percentile is below the LOD.

‡ Per the EA protocol, geometric means were not calculated for PFAS detected in less than 60% of samples.

Figure 2. Distribution of PFAS blood levels (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.

Community Statistics for PFAS in Blood Age-Adjusted to the Sampling Frame

Since the demographic profile comparison reported above showed that EA participants were significantly older than the sampling frame as a whole, ATSDR also calculated geometric means that were age-adjusted to the sampling frame population based on 2010 Census data for comparison. Age-adjusted geometric means correct for the participation bias discussed earlier and are more generalizable to the sampling frame community. Table 6 shows that age-adjusted blood geometric means for most PFAS are lower than unadjusted values. Of the three PFAS with the highest concentration (PFHxS, PFOS, and PFOA), age-adjusted geometric means are between 27% and 46% lower than unadjusted values. The lower values for age-adjusted geometric means reported here are consistent with older adults having higher blood PFAS levels than younger adults. The effect of age and the implications of these age-adjusted statistics are further discussed throughout this report.

Table 6. Geometric means for PFAS in blood in micrograms per liter, unadjusted and age-adjusted to the sampling frame

	Unadjusted		Age-Adjusted to Sampling Frame	
PFAS	Geometric Mean	95% CI for Geometric Mean	Geometric Mean	95% CI for Geometric Mean
PFHxS	11.7	7.66-17.7	6.37	4.59-8.85
PFOS	18.3	13.2-25.5	10.8	8.76-13.4
PFOA	2.12	1.78-2.52	1.55	1.38-1.74
PFNA	0.321	0.277-0.371	0.282	0.242-0.329
PFDA	NA*	NA*	NA*	NA*
PFUnA	NA*	NA*	NA*	NA*
MeFOSAA	0.136	0.113-0.166	0.141	0.104-0.190

CI = confidence interval. Results are based on 88 blood samples.

* Per the EA protocol, ATSDR did not calculate geometric means for PFAS detected in less than 60% of samples.

Comparison of EA Participants' PFAS Blood Levels to the National Population

This section compares PFAS levels among Moose Creek EA participants to levels found in the U.S. general population. To explore effects related to differences in the age distribution of EA participants vs. the NHANES population, ATSDR calculated both unadjusted geometric means of all EA participants and geometric means adjusted to the age distribution of the U.S. population in NHANES 2015–2016.

Table 7 shows the unadjusted comparison for the entire pool of EA participants to the geometric means for the 2015–2016 NHANES survey [CDC 2019]. For PFHxS, PFOS, PFOA, unadjusted geometric mean blood levels among Moose Creek EA participants were statistically ($p<0.05$) higher than the national geometric mean. For PFNA, the unadjusted blood levels among Moose Creek EA participants were statistically lower than the national geometric mean. Per protocol, geometric means were not calculated during NHANES for PFAS detected in less than 60% of samples, which included PFDA and PFUnA. In this EA, MeFOSAA was detected in more than 60% of samples and geometric means were calculated.

Of the PFAS analyzed in blood, PFHxS levels had the largest elevations when compared to national levels. The unadjusted geometric mean blood PFHxS level among Moose Creek EA participants was 9.9 times the national level. Blood PFHxS levels were above the national geometric mean for 96% of EA participants and above the NHANES 95th percentile for 73% of EA participants (Table 7). The unadjusted geometric mean blood PFOS level among Moose Creek EA participants was 3.9 times the national level. Blood PFOS levels were above the national geometric mean for 86% of EA participants and above the NHANES 95th percentile for 50% of EA participants. The unadjusted geometric mean blood PFOA level among Moose Creek EA participants was 1.4 times the national level. Blood PFOA levels were above the national geometric mean for 69% of EA participants and above the NHANES 95th percentile for 17%.

On average, total PFOS measurements were composed of 67% linear PFOS (n-PFOS) and 33% branched PFOS (Sm-PFOS). The proportion of n-PFOS found in EA participants' blood is lower than that found in standard PFOS products (76%–79%) [Kärrman et al. 2007] but comparable to levels found in the blood of the general U.S. population [CDC 2019]. Measurements of total PFOA were composed of 100% linear PFOA (n-PFOA), which is also comparable to the proportions found in the U.S. population [CDC 2019]. All remaining statistical analyses in this report focus on total PFOA and total PFOS rather than treating the linear and branched isomers separately.

For this EA, ATSDR also calculated geometric means age-adjusted to the NHANES population. Because the 2015–2016 NHANES survey does not report data for individuals under 12 years of age, these geometric mean calculations are based on 84 EA participants. Table 7 and Figure 3 show that blood PFAS geometric means adjusted to the NHANES population differ from unadjusted values. The adjusted geometric mean blood PFHxS level among Moose Creek EA participants was 7.7 times the national level. The age-adjusted geometric mean blood PFOS level among Moose Creek EA participants was 3.1 times the national level. Even when controlling for the age-distribution in the population, EA participants had statistically higher blood levels of PFHxS and PFOS than the U.S. population. After adjusting for age, blood levels of PFOA in EA participants were higher than the U.S. population, but the difference was not statistically significant.

Table 7. Comparison of PFAS blood geometric means (GMs) and 95th percentiles in Moose Creek, Alaska, with the U.S. population (NHANES 2015–2016) in micrograms per liter

PFAS	NHANES GM (CI)*	Moose Creek GM (CI)†: Unadjusted	Moose Creek GM (CI)†: Age-Adjusted to NHANES 2015-2016	Percent of Moose Creek Results over NHANES GM (%)	NHANES 95th Percentile*	Moose Creek 95th Percentile	Percent of Moose Creek Results over NHANES 95th Percentile (%)
PFHxS	1.18 (1.08–1.30)	11.7 (7.66–17.7) *p<0.001*	9.13 (6.55–12.7) *p<0.001*	95.5	4.90	115	72.7
PFOS	4.72 (4.40–5.07)	18.3 (13.2–25.5) *p<0.001*	14.6 (11.6–18.4) *p<0.001*	86.4	18.3	146	50.0
PFOA	1.56 (1.47–1.66)	2.12 (1.78–2.52) *p<0.001*	1.75 (1.56–1.98) *p=0.077*	69.3	4.17	8.73	17.1
PFNA	0.577 (0.535–0.623)	0.321 (0.277–0.371) *p<0.001*	0.275 (0.238–0.317) *p<0.001*‡	17.1	1.90	0.780	1.14
PFDA	0.154 (0.140–0.169)	NA§	NA§	23.9	0.700	0.330	0.00
PFUnA	NA§	NA§	NA§	NA	0.400	0.220	1.14
MeFOSAA	NA§	0.137 (0.113–0.166)¶	0.126 (0.107–0.150)¶	NA	0.600	0.580	4.55

CI = 95% confidence interval, NA = not applicable. Unadjusted results are based on 88 blood samples, and age-adjusted GMs are based on 84 blood samples.

* Source: CDC 2019

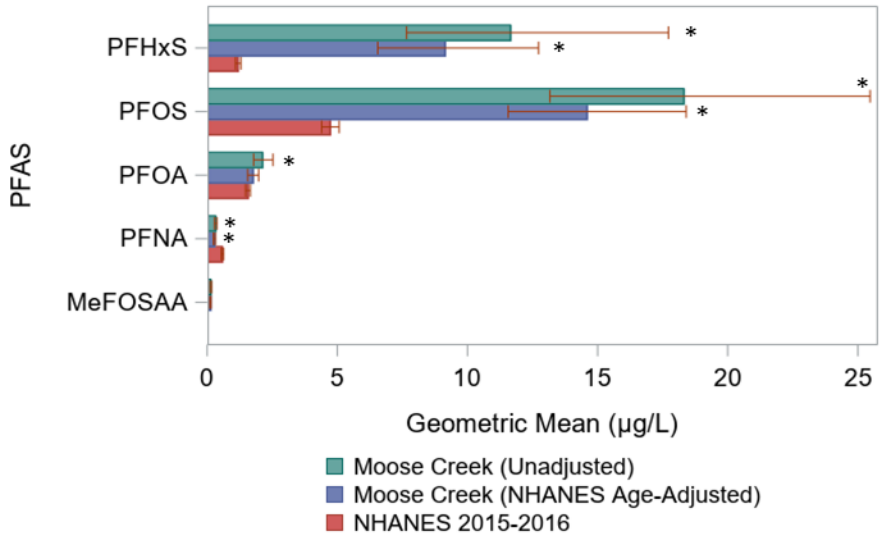
† P-values represent a t-test comparison between Moose Creek GM and NHANES GM.

‡ Statistically lower than NHANES 2015-2016 (p<0.05).

§ Per the protocol, geometric means were not calculated for PFAS detected in less than 60% of samples.

¶ No statistical comparison could be made with NHANES because NHANES did not calculate a geometric mean for this PFAS because this PFAS was detected in less than 60% of NHANES samples.

Figure 3. EA average PFAS blood levels compared to national levels



Error bars represent 95% confidence intervals. Note that overlapping confidence intervals do not mean that differences are not statistically significant.
**Statistically Significant Difference from NHANES (p<0.05)*

Correlations Among PFAS in Blood

ATSDR also evaluated correlations between PFAS in blood (log_{10}). This analysis determined whether any PFAS tended to have similar patterns in the blood of Moose Creek EA participants. ATSDR used Pearson correlation coefficients (*r*) for this analysis. An *r* of 0 means two data sets are uncorrelated, and an *r* of 1 means two data sets are exactly correlated (i.e., they rise and fall in proportional amounts). Table 8 shows the Pearson correlation coefficients for the five most frequently detected PFAS.

PFHxS, PFOS, and PFOA blood levels showed the strongest correlations (Table 8). All pairings of these chemicals had Pearson correlation coefficients close to 1 (*r* = 0.77–0.88). On the other hand, PFNA had weak to moderate correlations with other compounds (*r* = 0.27-0.54). MeFOSAA was only statistically correlated with PFNA, and that correlation was relatively weak (r=0.27).

Table 8. Pearson correlation coefficients between PFAS in blood (log)

	PFHxS	PFOS	PFOA	PFNA	MeFOSAA
PFHxS	1.00*	0.88*	0.78*	0.36*	0.08
PFOS	0.88*	1.00*	0.77*	0.54*	0.18
PFOA	0.78*	0.77*	1.00*	0.39*	0.13
PFNA	0.36*	0.54*	0.39*	1.00*	0.27*
MeFOSAA	0.08	0.18	0.13	0.27*	1.00*

* Statistically significant correlation (p<0.05)

PFAS Blood Levels by Demographics and Other Exposure Characteristics

This section examines how the demographic and exposure history information collected during the questionnaire relates to blood PFAS levels. See section "PFAS Blood Levels and Other Factors" for information about questions without enough responses for a meaningful statistical comparison. Since different questionnaires were administered to adult and child participants, responses were analyzed

separately. Additionally, some questions were applicable only to female adult participants and are therefore also presented separately. Appendix C (Tables C1 and C2) summarizes all adult and child questionnaire responses. Detailed analyses were not conducted for children because fewer than 10 children participated in this EA.

ATSDR used univariate and multivariate models to evaluate the relationships between questionnaire data and blood PFAS levels. This section summarizes relationships that were found to be statistically significant. For this EA, the following demographic and exposure characteristics had an association with at least one PFAS in either univariate or multivariate models:

- age,
- sex,
- tap water consumption,
- drinking water source,
- use of a water filtration or treatment device,
- length of residence in the sampling frame,
- private well contamination levels,
- soil exposure,
- occupational exposure,
- breastfeeding (adult females and children), and
- childbirth (adult females).

ATSDR created mathematical models to identify demographic and lifestyle characteristics associated with PFAS blood levels.

Univariate models evaluated the effects of one variable, or exposure characteristic, at a time while multivariable models evaluated the joint effect of multiple characteristics on blood PFAS levels at the same time. **Multivariable regression models** describe the average increases in PFAS blood levels for each unit increase in the exposure characteristics.

Table 9 summarizes the demographic and exposure characteristics that were statistically significant in each multivariate model.

Table 9. Summary of statistically significant variables (p<0.05) in multivariate regression models

Parameter	PFHxS			PFOS			PFOA		
	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male	All Adult	Adult Female	Adult Male
Age (continuous)	✓	—	✓	✓	✓	✓	✓	—	✓
Sex (categorical)	✓	NA	NA	✓	NA	NA	—	NA	NA
Age × sex (continuous)*	✓	NA	NA	✓	NA	NA	—	NA	NA
Maximum PFAS well concentration (continuous)	NA	NA	NA	✓	—	✓	✓	—	✓
Years in sampling frame in the past 20 years (continuous)	—	—	—	—	—	—	—	—	—
Drinking water source (categorical)	✓	—	✓	✓	✓	✓	—	—	—
Drinking water in cups per day (continuous)	✓	—	—	—	—	—	✓	—	✓
Occupational Exposure (categorical)	✓	—	✓	✓	—	✓	✓	—	✓
Soil Exposure (categorical)	—	—	—	✓	✓	✓	—	—	—
Breastfeeding (continuous)	NA	—	NA	NA	✓	NA	NA	—	NA

✓ = statistically significant, '—' = not statistically significant, NA = not applicable

* This variable is an interaction term, which means the effect of one variable on serum PFAS levels depends on the value of another.

The following subsections briefly summarize results for these topics. All other results are presented in Appendix C, as described below.

- Tables C1 and C2 present response frequencies for all questions included in the adult and child questionnaire, respectively. These tables also present geometric means and 95% confidence intervals around geometric means stratified by the response options (e.g., statistics are presented separately for males and females) for PFHxS, PFOS, PFOA, PFNA, and MeFOSAA. Geometric means and 95% confidence intervals are not presented for children because fewer than 10 children participated in this EA. While blood levels of PFNA and MeFOSAA were not found to be statistically higher than the national geometric means, both PFAS were detected at a high enough frequency to present meaningful results. Summary statistics are therefore provided in Appendix C for completeness, but not discussed below.

Goodness of Fit Measure

R-squared or R^2 is a statistical measure used to evaluate how well a mathematical model explains the measured data by looking at the differences between the observed PFAS concentrations and values predicted by the model.

- An R^2 of 1 means the model completely predicts the observed PFAS concentrations, so that there are no differences between the model and the PFAS concentrations and 100% of the PFAS concentrations are explained by the model.
- An R^2 of less than 1 means that there are measurements scattered higher and/or lower than the model predictions and there are differences between the two.

- Table C3 presents univariate modeling results for all questions in the adult questionnaire for the same five PFAS. Data are presented only when a category had at least 10 responses. Some categories were collapsed to meet this threshold. Univariate modeling results are not presented for children because fewer than 10 children participated in this EA.
- Tables C4–C10 present multivariate modeling results for PFHxS, PFOS, and PFOA. Multivariate models, including the goodness-of-fit measure, R-squared or R^2, are presented separately for all adults, male adults only, and female adults only. The closer the R^2 value is to 1, the more the variables in the model explain the variability in blood PFAS levels. Across all models, R^2 values ranged from 0.26 to 0.70. ATSDR modeled males and female adults separately to explore sex-specific differences including the potential effect of childbirth and breastfeeding on female blood PFAS levels. The variables considered in male-only and female-only models were limited to those that were significant in final all-adult models. Final multivariate male-only models and female-only models were only significant for PFHxS. ATSDR did not develop multivariate models for children because of the small sample size for this population (n=9).

> **Variability** describes the spread or dispersion of data values. If the values are similar to each other there is little variability, if the values are spread out there is more variability.
>
> Multivariable regression can help us understand how much of the variability in PFAS blood levels can be explained by the combination of factors in the model such as age, sex, and length of residency among others. If the model does not explain a large portion of the variability, that means there are other unknown factors influencing PFAS levels in blood.

- Figures C1–C24 present box and whisker plots for unadjusted blood levels by each demographic and exposure characteristic included in the statistical analyses.

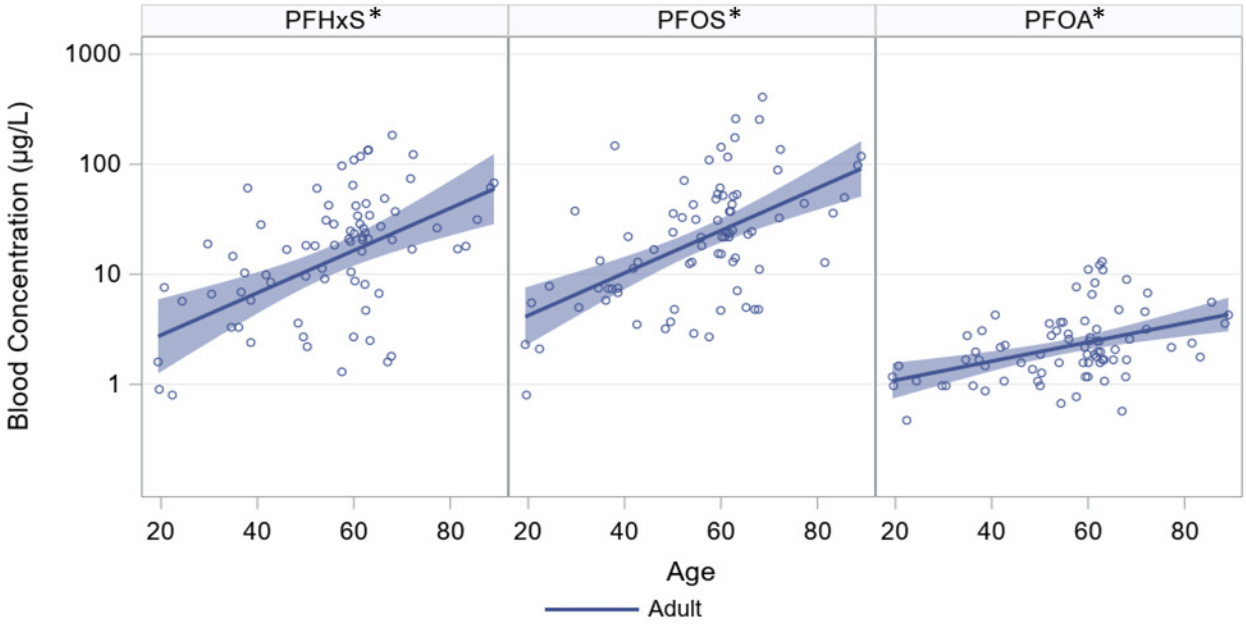
Blood PFAS Levels and Age

Because many studies have found that older people have higher blood PFAS levels, ATSDR investigated how Moose Creek EA participants' ages related to their blood levels. As Figure 4 illustrates, the blood levels for PFHxS, PFOS, and PFOA increased with age in adults.

For adults, ATSDR's univariate analysis showed that blood PFHxS, PFOS, and PFOA were higher in older individuals than in younger individuals, and this finding was statistically significant. As Figure 4 shows, PFHxS and PFOS had the strongest age dependence. The univariate analysis indicates that on average, blood levels of both PFHxS and PFOS increased by the same amount per year (4.5%) for every year of participant age for adults. This suggests a 55% increase in blood PFHxS and PFOS levels for every 10 years of participant age in adult participants. The calculated annual increase for PFOA (2.0% per year of participant age) was lower.

ATSDR's multivariate analysis provided further perspective on this trend, showing that the age dependence was generally stronger for women than men among adults for PFHxS and PFOS. For example, the all-adult models for PFHxS, PFOS, and PFOA (Appendix C, Tables C4 and C6) suggest a 6.8%, 7.3%, and 2.2% increase in blood PFHxS, PFOA, and PFOA levels, respectively, for every additional year of participant age in female participants, and a 4.4%, 3.8%, and 2.2% increase in blood PFHxS, PFOS, PFOA levels for every additional year of participant age in males, when controlling for other characteristics; these findings were statistically significant. Similar results were observed in the stratified male-only and female-only models. Age remained a significant predictor of blood levels for all three PFAS in all multivariate models, except for the PFOA female-only model.

Figure 4. PFAS blood levels in adults (log scale)



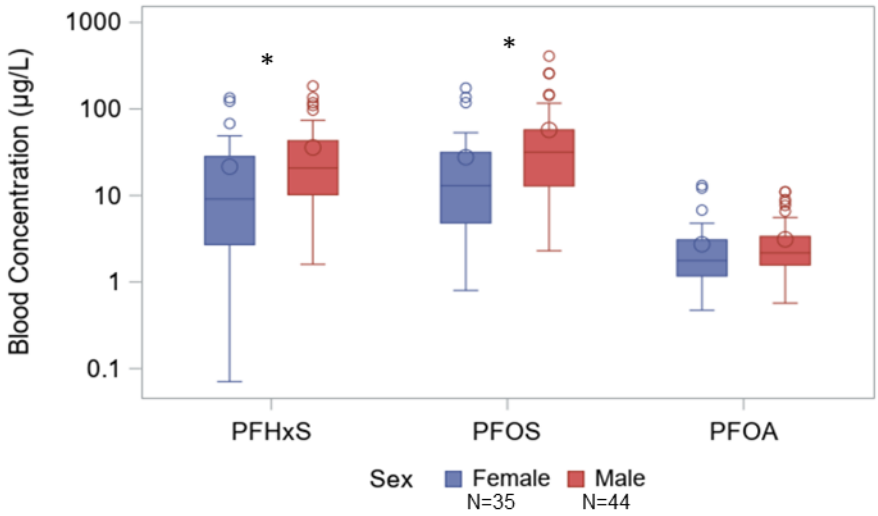
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend ($p<0.05$) in Adults*

Blood PFAS Levels by Sex

ATSDR investigated how blood PFAS levels vary between males and females because previous research has shown that, all other factors considered equal, adult males tend to have higher blood PFAS levels than adult females. ATSDR's univariate analyses showed that PFAS levels were higher in adult males than in adult females for PFHxS and PFOS. Modeled blood levels in adult males were 160% higher for PFHxS and 117% higher for PFOS (Figure 5).

The all-adult multivariate models showed that the difference between males and females was larger in younger people. For example, 30-year-old males had higher modeled blood PFHxS and PFOS levels than 30-year-old females by 196% and 272%, respectively. For 50-year-old participants, these differences were reduced to 88% for PFHxS and 95% for PFOS.

Figure 5. PFAS blood level in adults by sex (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Difference (p<0.05)*

Blood PFAS Levels and Tap Water Consumption

ATSDR investigated several questions from the adult questionnaire to characterize relationships between blood PFAS levels and consumption of PFAS-contaminated drinking water. These questions are about the drinking water source, use of filtration devices, amount of tap water consumed at home or school, and residential history. In some cases, data trends may have been affected by subtleties in the wording of exposure history questions, as described below. ATSDR also considered private drinking well testing results, using sampling data provided by the Air Force.

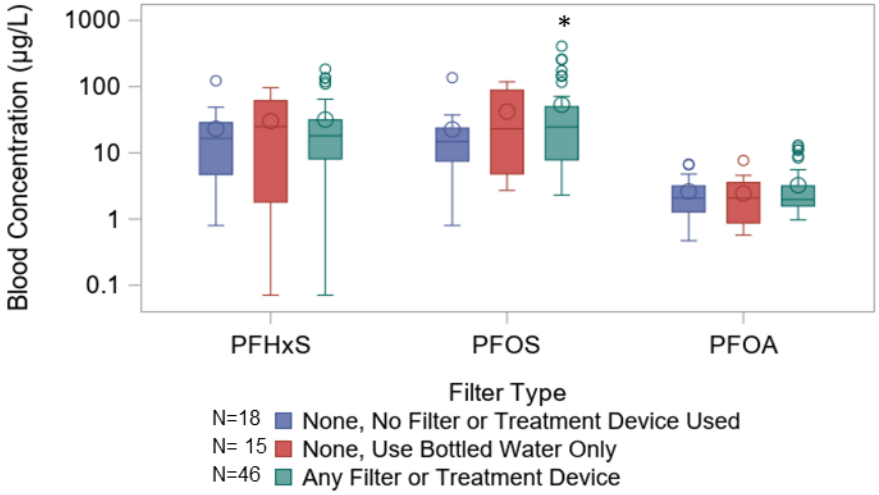
Drinking water source. For adults, ATSDR first considered participants' primary drinking water source. Adult participants were asked, "What is your current main source of drinking water in your home?" 41% said "public water system" (water supplied by the Air Force was recorded as "public water system" in the questionnaire); 38% said private well (most of which would have been treated with a GAC filtration system); and 22% said bottled water. There were no statistically significant differences in blood levels between these groups in univariate analyses. However, when controlling for other variables in multivariate analyses, participants who identified as currently primarily drinking bottled water had PFHxS levels 57% lower and PFOS levels 70% lower than those who primarily drank water from a private well. Participants who reported drinking primarily from a public water system had PFOS levels 59% lower than those who reported drinking primarily from a private well. Note that the exposure history question asked about current drinking water sources It is possible that some participants who reported currently drinking bottled water previously drank tap water when their private well was contaminated.

Use of filtration device. ATSDR also considered relationships between blood PFAS levels and current use of drinking water filtering and water treatment devices. 58% of participants reported using a filter or treatment device on the tap water that they drink at home (this includes the households equipped with GAC filtration systems and/or any other filter system), 23% of participants reported no filter or treatment device on the tap water that they drink at home, and 19% reported not drinking tap water at all. In ATSDR's univariate analyses (Figure 6), participants who reported using a filter or treatment device on the tap water that they drink at home on average had statistically greater blood levels of PFOS (83%)

when compared to participants who did not report using a filter. This may be due to households with higher historical PFAS concentrations being more likely to currently use a filtration device. In ATSDR's univariate analyses, participants who reported drinking bottled water did not have statistically different blood PFAS levels when compared to participants who drank tap water but did not use a filter.

When controlling for other variables in multivariate analyses, reported use of a filter or treatment device did not remain significant in models for any PFAS. While one would expect properly maintained filtering and treatment devices to decrease PFAS drinking water exposures, participants who reported not using a filter were likely receiving delivered water from the Air Force.

Figure 6. PFAS blood level in adults by filter type (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Difference (p<0.05)*

Consumption rates. ATSDR also considered participants' self-reported tap water consumption rates. Adult participants were asked, "During the time you lived in a home served by the water source identified above [i.e., for the question quoted three paragraphs ago], on average how many 8-ounce cups of water or beverages prepared with tap water did you drink while at home per day?" In univariate analyses, for every additional cup an adult reported drinking at home per day, blood PFHxS and PFOA increased by 4.1% and 2.5%, respectively. These associations remained significant in multivariate analyses, which controlled for other potential confounders. For every additional cup of tap water an adult reported drinking at home per day, PFHxS and PFOA levels increased by the same amount,

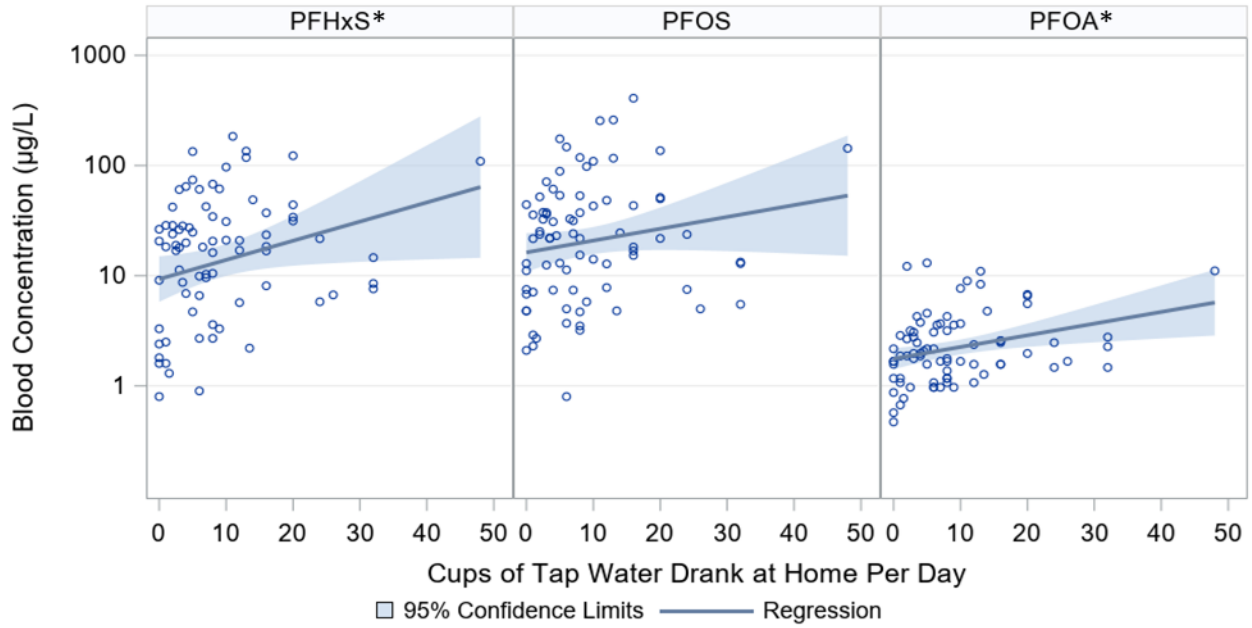
What are confounders?

Confounding is a distortion in the estimated relationship between a potential predictor and measure of exposure due to the presence of a third variable—called a confounder. In order for confounding to occur, that third variable must be associated with both the predictor (or independent variable) and the measure of exposure (or dependent variable). For example, age can act as a confounder on the estimated strength of association between length of residence in the sampling frame and blood PFAS levels.

By adjusting for these types of confounding variables in multivariate statistical models, ATSDR can calculate less biased estimates of the relationships between dependent and independent variables of interest.

2.3%, in an all-adult model. As can be seen in Figure 7, 22% of participants reported consumption rates that fall above the higher end values (95th percentile) reported in EPA's Exposure Factors Handbook of 3,292 milliliters per day (approximately 14 cups) [EPA 2019]. Because participants may have overestimated drinking water consumption rates, the effect estimates reported here should be interpreted with caution.

Figure 7. PFAS blood level in adults by tap water consumption rates (log scale)

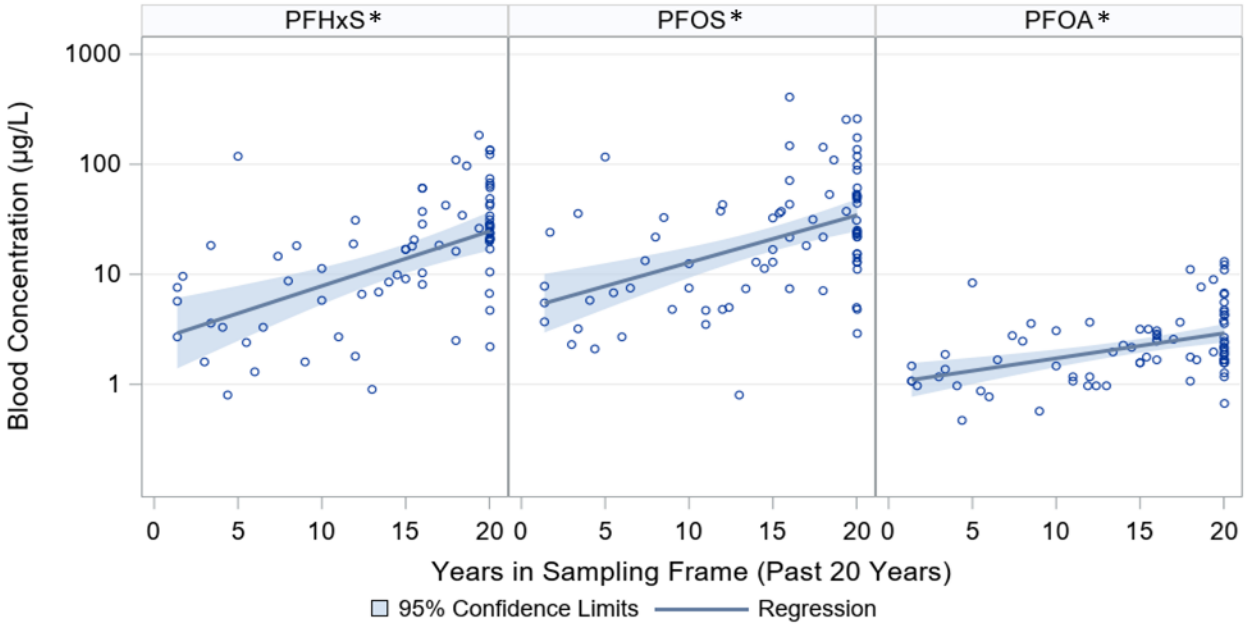


A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05)*

Length of residency. For adults, ATSDR also considered the length of residency. The exposure history questionnaire asked adults where they had lived for the past 20 years. ATSDR calculated the total amount of time participants reported living in the sampling frame over this period. These responses can serve as a proxy for potential exposure to PFAS-contaminated drinking water in the community. That is, the longer the residency within the sampling frame, the greater the likelihood of past PFAS exposure from contaminated drinking water. Any resident reporting prior residences with addresses in "Moose Creek, AK" were assumed to fall within the sampling frame. All addresses in "North Pole, AK" were mapped and categorized as within or outside of the sampling frame accordingly.

Figure 8 shows the relationship between reported residence duration in the sampling frame for the past 20 years and blood PFAS levels. Blood levels statistically increased with the number of years participants lived in the sampling frame in the past 20 years for PFHxS (12.1% per year), PFOS (10.4% per year), and PFOA (5.4% per year). However, these relationships did not remain statistically significant in multivariate regression models.

Figure 8. PFAS blood levels in adults by length of residence in sampling frame (log scale)



A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05)*

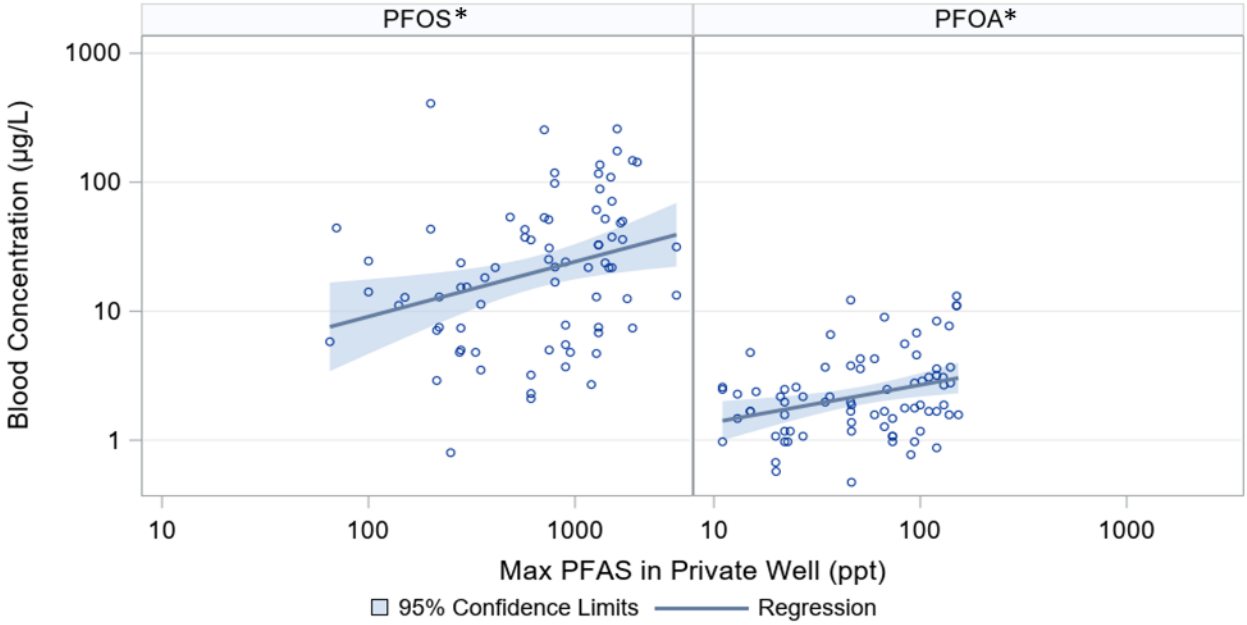
Private well testing data. ATSDR also considered private well testing data obtained from the Air Force. ATSDR linked EA participant households to corresponding households with private wells that were sampled by the Air Force between 2015 and 2017 Since the Air Force conducted multiple rounds of testing in certain households, ATSDR assigned the maximum concentration measured at a household's private well to each participant in that household for its analysis. ATSDR was able to assign private well contamination levels to 85 out of 88 participants (97%) in this EA. PFOS and PFOA were the only PFAS reported by the Air Force in these samples and both compounds were detected in 100% of participants' wells. The maximum concentrations measured in drinking water wells of EA participants were 3,100 ppt for PFOS, and 153 ppt for PFOA. Note that 3,100 ppt represents the highest PFOS concentration measured by the Air Force across all Moose Creek samples, including non-EA households; and 153 ppt is lower than the maximum PFOA concentration of 250 ppt measured in a non-EA household.

For adults, in univariate models, the log of maximum PFOS and PFOA well water concentrations were statistically associated with blood PFAS levels (Figure 9). Comparisons were made only between like PFAS. For example, the effect of PFOS well water concentrations were only compared with blood PFOS levels. For each 1% increase in maximum PFOS well water concentration, blood PFOS levels increased on average by 0.43%. For each 1% increase in maximum PFOA well water concentration, blood PFOA levels increased on average by 0.29%. wherein the multivariate analyses, for each 1% increase in maximum PFOS and PFOA well water concentration, there was a corresponding increase in blood PFOS (0.22%) and PFOA (0.27%), respectively.

PFOS and PFOA were detected in Moose Creek private wells (PFOS at a maximum of 3,100 ppt and PFOA at a maximum of 153 ppt in EA participant wells). PFHxS, PFOS, and PFOA were highly correlated in blood measurements. Therefore, one explanation for the high correlation among these compounds in the blood is that the Moose Creek EA participants had a common exposure profile for these PFAS, such

as drinking water. However, the correlations alone cannot be used to identify the underlying source or combination of sources that contributed most to exposure.

Figure 9. PFAS blood levels in adults by maximum PFAS in private well (log scale)

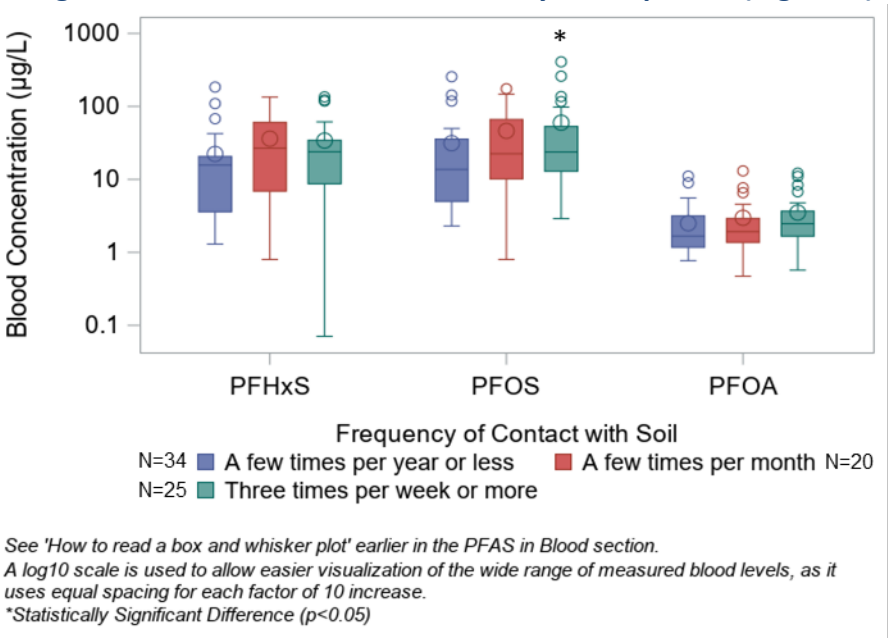


A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Trend (p<0.05)*

Blood PFAS Levels and Soil Exposure

Adult participants were asked how often they touch soil or dirt in the sampling frame. Among adult participants, 34 reported coming into contact with soil a few times per year or less (43%), 20 reported a few times per month (25%), and 25 reported three times per week or more (32%). Adult participants who reported coming in contact with soil within the sampling frame three times per week or more on average had blood PFOS levels 88% greater than those who reported contacting soil within the sampling frame a few times per year or less (Figure 10). This association remained significant in multivariate models where participants who reported coming in contact with soil within the sampling frame a few times per month (99%) and three times per week or more (93%) on average had blood PFOS levels greater than those who reported coming in contact with soil within the sampling frame a few times per year or less.

Figure 10. PFAS blood level in adults by soil exposure (log scale)



See 'How to read a box and whisker plot' earlier in the PFAS in Blood section.
A log10 scale is used to allow easier visualization of the wide range of measured blood levels, as it uses equal spacing for each factor of 10 increase.
**Statistically Significant Difference (p<0.05)*

Blood PFAS Levels and Occupational Exposures

Adult participants were asked about their occupational history over the past 20 years. Participants were specifically asked about experience working at manufacturers of PFAS or PFAS-containing products (e.g., nonstick cookware, water-resistant clothing) and past work in firefighting, the military, or aviation. 23 (29%) adult participants reported at least one occupational exposure in the past 20 years. All 23 participants reported working in either military, aviation, or firefighting. In univariate analyses, participants with occupational exposures on average had greater blood PFHxS (239%), PFOS (151%), and PFOA (63%) levels than adult participants who reported no occupational exposures in the past 20 years.

Occupational exposures remained statistically associated with blood PFAS levels in multivariate models. In all-adult models, participants who reported at least one occupational exposure had greater blood PFHxS (180%), PFOS (96%), and PFOA (58%) levels than adult participants who reported no occupational exposures in the past 20 years.

Blood PFAS Levels and Breastfeeding

During breastfeeding, some PFAS in the breast milk might be transferred from mother to child Therefore, breastfeeding might reduce PFAS levels in mothers and increase PFAS levels in their breastfed children [Kim 2020; Kingsley 2018]. Accordingly, the adult and child exposure history questionnaires included questions about breastfeeding. A question was also included for children about their consumption of formula (as opposed to breast milk), and if the formula was made using tap water.

Among adult female EA participants, 71% reported that they had breastfed a child, with an average breastfeeding duration across all pregnancies of 15 months. In univariate models for adult females, having ever breastfed a child (yes/no) was not associated with PFAS serum levels in univariate models. Total breastfeeding duration was associated with PFAS serum levels in univariate models; every one-month increase in breastfeeding duration was associated with a 1.8% decrease in blood PFOS levels. In female-only multivariate models, this association remained statistically significant: for every one-month increase in breastfeeding duration blood PFOS levels decreased by 1.5%, respectively.

Blood PFAS Levels and Other Variables

Through the exposure history questionnaires, ATSDR gathered information on several other possible contributing factors to PFAS exposures. The variables listed below were not statistically associated with blood levels of PFHxS, PFOA, and PFOS among EA study participants in univariate or multivariate analyses. In some cases, ATSDR was not able to assess particular relationships because of small number of participant responses.

- **Race/Ethnicity.** Adult and child participants were asked to provide information about their race and ethnicity. However, because there were not enough participants in different race and ethnicity categories to support robust statistical analyses, ATSDR focused on differences between Moose Creek EA participants who self-identified as White, non-Hispanic and those who identified as non-White, or Hispanic. No statistical relationship was observed for self-reported race/ethnicity and blood PFAS level in adults.
- **Water treatment intervention.** ATSDR considered whether the type of water treatment provided by the Air Force was associated with PFAS blood levels in adults. The Air Force provided 58% (n=46) of participants delivered water and 41% (n=32) of participants granular activated carbon (GAC) systems. One percent of participants (n=1) did not receive a water treatment technology or intervention because the sampling on their property did not reveal PFAS concentrations above the EPA HA or AK DEC Action Levels. ATSDR also considered the date of the water treatment installation or intervention by the Air Force. Neither the water treatment type variable nor the days since treatment was provided was associated with blood PFAS levels.
- **Blood donation frequency.** Adult participants were asked how often they donate blood or plasma, because frequent blood and plasma donations might result in decreasing blood PFAS levels. ATSDR was unable to evaluate the effect of this variable on blood PFAS levels because of the small number of participants who reported that they donated blood once or more per year (n=5).
- **Kidney disease.** The exposure history questionnaire asked about kidney disease because it can affect blood PFAS levels [Barry et al. 2013; Watkins 2013]. The questionnaire results indicated that only 4% of adults (n=3) reported a diagnosis of kidney disease; due to this limited sample size, ATSDR was unable to evaluate the effect of this variable on blood PFAS levels. Note that kidney disease was self-reported and there may be misclassification with this variable.
- **Consumption of selected local food items.** Some PFAS accumulate in plants, fish, and animals. The questionnaire asked adult and child participants how often they consume locally grown fruits and vegetables, locally caught fish, and milk from animals in the sampling frame. A statistically significant relationship was not observed between consumption of locally grown fruits and vegetables and blood PFAS levels. Too few adult EA participants reported consuming locally caught fish (n=6) or locally produced milk (n=2) to allow for meaningful statistical comparison to blood PFAS levels.
- **Cleaning frequency.** Adult participants were asked how often their homes are cleaned. No statistically significant relationship was observed for self-reported cleaning frequency and blood PFAS levels in adults.
- **Stain-resistant product use.** Many stain-resistant products used to treat fabrics and carpet have been formulated with PFAS. The exposure history questionnaire asked adult participants how frequently they used these products; such uses may be associated with PFAS exposures. Moose Creek EA adult participants with any self-reported stain-resistant product use did not have

statistically elevated blood levels of any PFAS when compared to participants who reported never using these products.

- **Flooring.** Adult participants were asked about the type of flooring in their living rooms, kitchens, and bedrooms. While carpet has been linked to increased PFAS exposure because PFAS-containing stain- and grease-repelling coatings are often applied to carpet [Beesoon et al. 2012], the presence of carpet in EA participants' rooms was not statistically associated with blood PFAS levels among adults.
- **Fast food consumption.** PFAS may be present in fast food take-away containers and food packaging. Consumption of fast food may serve as an additional source of PFAS exposure. However, among Moose Creek EA adult participants, reported frequency of fast food consumption was not statistically associated with blood PFAS levels. In recent years, fast food packaging has likely been reformulated to contain shorter chain PFAS compounds. This shift may make it more challenging to link PFAS exposure to fast food consumption.
- **Childbirth (adult females) and birth order (children only).** Adult female participants were asked whether they had any biological children, and if so, how many. Children were asked their birth order. Pregnancy may lead to lower blood PFAS levels for mothers, and birth order may be related to PFAS levels in children (with first-born children having higher PFAS levels than last-born children). Most adult female EA participants (89%) reported having biological children. However, ATSDR was unable to evaluate this variable because of the small number of adult female participants that reported no biological children (n=4). The number of children was not statistically associated with blood PFAS levels.

PFAS in Urine

The study protocol calls for ATSDR to initially analyze 10% of urine samples collected. The protocol indicates that ATSDR will analyze all participants' urine samples if the initial analysis shows geometric mean urine concentrations of any PFAS greater than the NHANES 95th percentile values; however, this threshold was not met. Note that only PFBA and PFHxA were detected in more than 5% of the NHANES samples.

For the Moose Creek EA, ATSDR randomly selected 9 participants' urine samples for analysis. The samples used for summary statistics were provided by 8 adults and 1 child, and these individuals lived in 9 different households. No PFAS were detected in any of the 9 urine samples. Since no PFAS were detected, no summary statistics were calculated for any PFAS in urine and ATSDR did not analyze the remainder of the urine samples.

Information on urinary concentrations of PFAS in humans is limited, yet it may be important to understand exposure to short-chain and alternative PFAS. Because urine is the primary route of excretion for many PFAS, urinary concentrations may reflect more recent exposures than do serum concentrations. In this EA, PFAS were detected in serum but not in urine. These results highlight the importance of using the appropriate biomonitoring matrix for assessing exposures. Concentrations of biologically persistent compounds (like some PFAS) are expected to be higher in serum than in urine, as was observed in this assessment. This trend is also evident in other biomonitoring studies in the general population and in communities with known PFAS exposures [Calafat et al. 2019].

PFAS in Tap Water

As noted previously, ATSDR collected tap water samples from 13 randomly selected EA participant households and analyzed these samples for PFAS. Three households only provided an unfiltered water

sample, four households only provided a filtered well water sample, one household provided two filtered well water samples, and five households provided filtered and unfiltered water samples. Detection limits were 2 ppt for all PFAS, except for HFPO-DA (5 ppt). One of the unfiltered samples was from an outdoor spigot that does not serve as a drinking water source.

Filtered samples. Low levels of five PFAS (PFBS, PFHxA, PFHxS, PFOA, and PFOS) were detected in one of eleven filtered water samples taken from ten households. The low-level detection was below the EPA HA and AK DEC Action Levels. The detections were from a sample taken from a refrigerator filter in a household receiving delivered water. The corresponding unfiltered sample was non-detect. Why more PFAS were detected in a filtered sample is unclear, as one might assume that filtered water would be less contaminated than unfiltered water. A possible explanation is related to filter maintenance, though this issue could not be fully explored as part of this assessment.

PFAS were not detected in the remaining filtered samples. Eight samples were from households with a whole-house GAC filtration system installed by the Air Force. In some cases, these households had additional point of use filters such as an under the sink or refrigerator filter. One sample was taken from a household that received delivered water but had additional point of use filters. Two samples were from a household that did not have elevated PFAS levels that triggered an intervention by the Air Force, but this household had a separate point of use filter.

Unfiltered samples. Three PFAS (PFBS, PFHxA, and PFHxS) were detected in seven of the seven unfiltered water drinking water samples collected at seven households. PFHpA was detected in one sample, PFOA in five samples, and PFOS in four samples. All of the detections in these unfiltered samples were below the EPA HA and AK DEC Action Levels. Six samples were from delivered water and the seventh was well water from a household that had a point of use filter.

Table 10 shows the range and detection frequencies in filtered and unfiltered water samples.

Table 10. Summary statistics for tap water samples collected during the Moose Creek EA

PFAS	Filtered Samples (n=11)*		Unfiltered Samples (n=7)†	
	Frequency of Detection (%)	Range of Concentrations (ppt)	Frequency of Detection (%)	Range of Concentrations (ppt)
PFBS	9	ND–2.2	100	2.1–6.1
PFHpA	0	ND	14	ND–3.2
PFHxA	9	ND–3	100	2.3–7.5
PFHxS	9	ND–5.8	100	4.9–43
PFOA	9	ND–3	71	ND–9.6
PFOS	9	ND–2.7	57	ND–46

ND = not detected

* The filtered water samples category consists of 8 samples collected after Air Force-installed whole house treatment systems and 3 after other point-of-use filtration.

† The unfiltered water samples category consists of 6 samples of Air Force-delivered water and 1 prior to filtration. It does not include the unfiltered sample collected from an outdoor spigot at one household (non-drinking water source).

ATSDR also collected one unfiltered sample from an outdoor spigot at an EA participant household, and one unfiltered sample from the tap of a non-residential building in the sampling frame (these samples are not summarized in Table 10). These samples represent unfiltered private well water in the sampling frame. PFBS, PFHpA, PFHxS, PFOA, PFOS, and PFHxA were detected in these samples, and the PFOS concentrations were 230 and 290 ppt, greater than the EPA HA and AK DEC Action Level of 70 ppt. However, neither water source was used for drinking water.

Overall, the three unfiltered well samples (two from EA households and one from the non-residential building) suggest that the groundwater in parts of the sampling frame remains contaminated with PFAS. However, based on the samples ATSDR collected, no drinking water samples contained PFAS at levels that exceed the EPA HA or AK DEC Action Levels.

PFAS in Household Dust

ATSDR collected dust samples from the same 13 randomly selected participant households where tap water samples were collected and analyzed these samples for PFAS. These samples were taken from multiple locations in each household, including the primary living space as identified by the homeowner (e.g., living room, family room, television room), the kitchen, and the bedroom in which participants reported spending the most time. When necessary, additional sampling was performed in other rooms to allow ATSDR to collect the proper amount of dust for testing.

Table 11 lists the specific PFAS that were measured in dust along with detailed summary statistics (i.e., frequency of detection, geometric means, 95% confidence intervals around the geometric means, and percentiles). Note that several PFAS were not detected in any sample and are therefore not included in Table 11 (i.e., PFNS, N-EtFOSA, FtS 4:2, HFPO-DA, ADONA, 9CL-PF3ONS, and 11CL-PF3OUdS).

Table 11. Summary statistics for dust samples (n=13) collected in Moose Creek

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50th (Median)	90th	95th
PFBS	38	2.38	NA*	NA*	0.625	2.31	2.36
PFPeS	8	2.37	NA*	NA*	0.402	1.36	1.86
PFHxS	69	46.9	2.55	1.06–6.12	3.07	9.38	22.6
PFHpS	8	2.35	NA*	NA*	0.426	1.35	1.85
PFOS	100	28.2	8.35	5.58–12.5	7.00	20.7	25.0
PFDS	38	13.6	NA*	NA*	0.782	2.15	6.29
PFDoS	23	2.35	NA*	NA*	0.475	1.46	1.85
PFBA	54	9.40	NA*	NA*	2.91	6.24	7.38
PFPeA	38	4.72	NA*	NA*	1.26	4.33	4.54
PFHxA	77	15.2	2.56	1.37–4.81	2.16	10.3	12.7
PFHpA	69	21.3	2.23	1.03–4.85	2.16	11.8	16.3
PFOA	85	23.5	4.06	2.52–6.55	3.14	11.2	17.1
PFNA	85	11.4	3.06	2.00–4.66	2.38	9.61	11.1
PFDA	85	6.36	1.98	1.26–3.10	2.04	3.87	4.86
PFUnA	62	4.83	1.07	0.639–1.80	0.811	2.73	3.47
PFDoA	62	22.2	1.42	0.722–2.80	1.58	3.02	9.92

PFAS	FOD (%)	Maximum Detected Result (ng/g)	Geometric Mean (ng/g)	95% Confidence Interval for Geometric Mean (ng/g)	Percentiles (ng/g)		
					50th (Median)	90th	95th
PFTrA	46	4.00	NA*	NA*	0.693	2.33	2.93
PFTA	46	12.8	NA*	NA*	0.908	2.12	6.01
PFOSA	31	2.35	NA*	NA*	0.645	2.07	2.29
N-MeFOSA	31	2.71	NA*	NA*	0.649	2.15	2.44
MeFOSAA	69	18.2	1.83	0.897–3.73	1.10	9.85	13.9
N-MeFOSE	69	145	17.1	8.93–32.6	13.1	76.5	112
EtFOSAA	92	13.4	2.92	1.65–5.16	2.14	11.8	12.7
N-EtFOSE	38	22.0	NA*	NA*	3.92	15.9	19.1
FtS 6:2	100	81.3	12.2	6.10–24.2	9.60	55.3	69.3
FtS 8:2	23	17.3	NA*	NA*	1.71	8.47	12.2

FOD = frequency of detection, ng/g = nanograms per gram, NA = not applicable
A total of 13 dust samples are summarized in this table.
* Per the EA protocol, geometric means were not calculated for PFAS detected in less than 60% of samples.

N-MeFOSE and FtS 6:2 were detected at the highest concentrations. M-MeFOSE and FtS 6:2 had geometric mean values of 17.1 nanograms/gram (ng/g)[4] (95% confidence interval = 8.9–32.6 ng/g) and 12.2 ng/g (95% confidence interval = 6.1–24.2 ng/g). PFHxS, PFOS, and PFOA were detected in 69%, 100%, and 85% of the households evaluated, respectively. PFHxS, PFOS, and PFOA had geometric mean values of 2.5 nanograms/gram (ng/g) (95% confidence interval = 1.1–6.1 ng/g), 8.3 ng/g (95% confidence interval = 5.6–12.5 ng/g), and 4.1 ng/g (95% confidence interval = 2.5–6.5 ng/g), respectively. PFHxA, PFHpA, PFNA, PFDA, PFUnA, PFDoA, MeFOSAA, and EtFOSAA were also detected in greater than 60% of samples. Geometric means were not calculated for any other PFAS because these PFAS were detected in less than 60% of samples.

To provide some context to the results summarized above, average levels of PFAS measured in the 13 samples collected as part of this EA were compared to average dust levels reported in other U.S.-based studies (in communities with or without PFAS contamination). This includes evaluations of indoor dust collected at 30 homes in the greater Boston area [Fraser et al. 2013], 124 homes in California [Wu 2015], 15 U.S. homes [Karásková et al. 2016], and 19 homes in Minnesota cities with PFAS-contaminated soil and drinking water [Scher et al. 2018]. Across these studies, PFOA and PFOS were consistently reported at the highest concentrations. Geometric mean concentrations ranged from 24 to 45 ng/g for PFOA and 27 to 35 ng/g for PFOS [Fraser et al. 2013; Wu et al. 2015]. Two of the studies did not report geometric means; for these studies, median concentrations were reported at 9 ng/g and 51 ng/g for PFOA and 14 ng/g and 67 ng/g for PFOS [Karásková et al. 2016 and Scher et al. 2018, respectively]. Geometric mean and median concentrations for PFOA and PFOS measured in the 13 samples collected as part of this EA

[4] This unit (in this case, representing nanograms of PFAS measured per gram of dust collected) is equivalent to parts per billion and micrograms per kilogram.

were lower than what was reported from these four studies. Details on these studies and comparisons with all other measured PFAS can be found in Appendix A, Table A1.

While these results suggest that PFOS and PFOA measured in the dust samples collected in Moose Creek were found at lower levels than reported elsewhere in the United States, note that the studies referenced here do not necessarily provide representative comparisons and are provided only for additional context. The sample collection methods and analytical methods were also not consistent among these studies.

ATSDR also evaluated the correlation between PFAS measured in dust and blood. This analysis included analytical data from 13 dust samples and from the 25 blood samples collected from participants residing in the same homes. Using log-transformed data, ATSDR calculated Pearson correlation coefficients for the PFAS measured in at least 60% of the dust and the same PFAS measured blood samples for this assessment. Data were log-transformed because dust and blood concentrations were log-normally distributed.

PFOS measured in dust was statistically correlated (r=0.56, p=0.0036) with PFOS measured in blood. MeFOSAA measured in dust was statistically correlated (r=0.64, p=0.0005) with MeFOSAA measured in blood. None of the other PFAS measured in dust were statistically correlated ($p<0.05$) with the same PFAS measured in blood. Note that the sample size for dust measurements in Moose Creek is small. ATSDR will further explore these findings, as well as correlations between different PFAS measured in dust and blood (e.g., the correlation between PFOA in dust and PFOS in blood) in the report for all ATSDR PFAS EA sites.

The dust results presented here are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample mass. The target sample mass for this study was 1 gram, but this target was not always met. Results based on less than 1 gram of dust have higher detection limits, a possible source of bias.

Discussion

At least one PFAS was detected in the blood of all Moose Creek EA participants (100%). Because of the widespread use of PFAS, such high detection frequencies are common in the general U.S. population [CDC 2019]. PFHxS, PFOS, PFOA, PFNA, and MeFOSAA were the most frequently detected compounds in Moose Creek EA participants (detection frequencies above 70%).

Results from this EA were compared to the NHANES data from 2015–2016.[5] Age-adjusted geometric mean blood levels of PFHxS and PFOS were statistically higher than these national geometric means (7.7 and 3.1 times the national level, respectively), and age-adjusted blood concentrations of PFOA and PFNA were similar to or lower than national geometric means. ATSDR was unable to compare blood levels of MeFOSAA because this PFAS was detected in less than 60% of NHANES samples. EA participants had statistically higher blood PFHxS and PFOS levels than national levels.

[5] Newer NHANES data are now available, but this report (and all individual EA reports) compares EA results to 2015-2016 NHANES data to be consistent with individual results letters provided to participants. ATSDR will consider including the newer data in the report analyzing data across all EA sites.

All PFAS measured in blood for this EA have been phased out of production in the United States. Following this phase-out, national blood PFAS levels have been steadily declining since 2000 [CDC 2019]. Differences between geometric mean Moose Creek EA blood levels, collected in 2020, and the NHANES 2019-2020 geometric mean (not yet available) could be greater than the differences between geometric mean Moose Creek EA blood levels and the NHANES 2015-2016 geometric mean presented here.

ATSDR compiled blood PFAS levels for the three most prevalent PFAS (PFHxS, PFOS, and PFOA) to provide further context on the current (2020) Moose Creek EA blood levels (Appendix A, Table A2):

- For PFOS and PFOA, blood levels among Moose Creek EA participants are within the range of those observed in other communities with contaminated drinking water (Appendix A, Table A2).
- Moose Creek EA participants' blood PFHxS levels are higher than the national geometric mean from 1999–2000, the time NHANES first measured PFAS and the time the highest PFAS levels were observed [CDC 2019]. EA participants blood PFHxS levels are also higher than levels observed in other communities with contaminated drinking water [PA DOH 2019; ATSDR 2013; Frisbee et al. 2009; NH DHHS 2016; NYDOH 2019].

Generalizability of Moose Creek EA Community Statistics

The recruitment method used for this EA was designed to produce summary statistics of blood PFAS levels that were generalizable to the sampling frame as a whole (i.e., Moose Creek households in the area shown in Figure 1). Although all households in the sampling frame were invited to participate in this EA, the population that ultimately enrolled was older. Specifically, adults aged 50 or older represented 65% of the EA population compared with 24% of the sampling frame. The EA population and the sampling frame as a whole did not statistically differ in the proportion of people who identify as White. Given the 15% response rate, it is also possible that other factors were present at different rates than the community as a whole.

Since age was associated with blood PFAS levels in univariate analyses, the summary statistics for blood PFAS (Table 5) may be biased, or deviate from the true value, when generalizing to the entire sampling frame. ATSDR believes that any bias caused by differences in ethnicity would be minimal because race and ethnicity were not statistically significant in multivariate analyses for PFHxS, PFOS, and PFOA. However, ATSDR was concerned about the potential bias caused by the older age of EA participants since levels of PFAS are known to vary depending on people's age. Therefore, ATSDR quantified the magnitude of the bias introduced by age by calculating geometric means that were adjusted to the age distribution of the sampling frame (Table 6). This analysis showed that the unadjusted geometric means for blood PFHxS, PFOS, and PFOA biased high by 21% to 28%. Therefore, the sampling frame age-adjusted geometric means for PFAS are more representative of the average levels in the community.

Relationships Between Demographics and PFAS Blood Levels

When evaluating differences in demographic factors by PFAS levels, adult males had statistically higher geometric mean blood levels for PFHxS and PFOS, based on results from the all-adult multivariate models, but did not have statistically elevated differences for other PFAS. In other studies in communities with contaminated drinking water and for the general U.S. population [e.g., ATSDR 2013; NH DPHS 2016; CDC 2019], sex-based differences are likely due to additional excretion routes in females including through menstrual fluid, breastfeeding, pregnancy, and renal clearance rate differences [ATSDR 2021]. PFAS have been demonstrated to pass through the placental barrier and into the developing fetus during gestation, and have been measured in maternal serum, cord blood, breast milk [Cariou et al. 2015], placenta [Chen et al. 2017], fetal tissue [Mamsen et al. 2019], and neonates [Wang

et al. 2014]. These studies suggest gestation, birth, and breastfeeding as excretion pathways for mothers and gestation and breastfeeding as potential exposure pathways for infants. In this EA, the effect of gestation (as measured by the number of children a female reported having had) was not a significant predictor of PFAS blood levels, but the duration of breastfeeding was found to be statistically associated with decreasing blood levels of PFOS among adult women. ATSDR was unable to evaluate the effect of breastfeeding or birth order on PFAS blood levels in children because of the small sample size (n=9).

Blood PFAS levels were statistically higher in older adults than younger adults, and the effect of age was stronger in female participants than males for PFOA. ATSDR was unable to evaluate the effect of age on PFAS blood levels in children because of the small sample size. Generally, increasing blood levels in adults are due to the long biological half-lives of PFAS and diminishing excretion rates with increasing age. The half-life of a chemical is the amount of time it takes for 50% of the substance to be eliminated from the body. Some studies estimate that the half-life of PFHxS is between 4.7 and 35 years. Half-life estimates range from 3.3 to 27 years for PFOS and from 2.1 to 10.1 years for PFOA. In the presence of continued exposures that exceed clearance rates, PFAS will accumulate in the human body over time.

Significance of Drinking Water Exposures

ATSDR conducted EAs to learn more about how exposure to PFAS-contaminated drinking water affects blood PFAS levels. This relationship is complicated because EA participants were likely exposed to PFAS not only in contaminated drinking water but also in various consumer products and food items unrelated to the water. ATSDR considered the following lines of evidence to understand the potential significance of the drinking water exposure pathway:

- PFHxS and PFOS blood levels in EA participants were statistically higher than national geometric means. PFAS were first detected in Moose Creek private wells in 2015. We do not know if contamination began earlier because no data are available before 2015. Among the site documents ATSDR reviewed, the highest sampling result from private wells in Moose Creek was 3,100 ppt for PFOS and 250 ppt for PFOA. PFHxS measurements in drinking water wells were not available. However, measurements taken from unfiltered water samples in this EA indicate that PFHxS is currently present in groundwater in Moose Creek at levels above PFOA and below PFOS. The maximum concentrations measured in unfiltered well water in this EA were 130 ppt for PFHxS, 290 ppt for PFOS, 36 ppt for PFOA. The information available to ATSDR indicates that the last time the Air Force measured PFAS drinking water concentrations in a private well above EPA's HA or AK DEC's Action Level was in December 2017. However, these PFAS have long biological half-lives (2.1 to 35 years). Therefore, even though drinking water PFAS exposures in private wells were significantly reduced by December 2017, past drinking water exposures would contribute to the EA participants' elevated blood PFAS levels observed 2 years and 8 months later. Furthermore, in this EA, PFHxS blood levels exceeded the national levels by the greatest margin (7.7 times higher when adjusted for age) and showed the greatest association with reported drinking water consumption, which is what would be expected given that PFHxS has the longer half-life of the two PFAS. PFOS blood levels when adjusted for age were 3.1 times the national average.
- The strongest evidence linking blood PFAS levels to drinking water exposures is the consistent and strong association observed with historical maximum concentrations of PFAS measured in each household's private well. Drinking water measurements provided by the Air Force indicate that maximum concentrations of PFOS and PFOA for households in this EA were 3,100 ppt, and 153 ppt, respectively. (Note that the previously reported maximum PFOA concentration of 250 ppt was measured in a household that did not participate in the EA). The Air Force did not

provide PFHxS measurements to ATSDR. For PFOS and PFOA, the individual drinking water measurements were statistically associated with corresponding PFAS measured in blood (Figure 9). In other words, residents of households that had the highest private well contamination for PFOS and PFOA generally had higher blood levels for these substances. These results further suggest that elevated blood PFOS levels were due to PFAS-contaminated drinking water. Average blood PFOA levels were not statistically elevated compared to national levels, however, the association observed between levels in drinking water and blood were still significant. This observation may be explained by the fact that PFOA was detected in the wells of participants at much lower concentrations than PFOS.

- EA participants living in Moose Creek longest have the highest PFAS levels. Univariate statistical analyses of the EA data found that a consistent predictor of adult blood PFHxS, PFOS, and PFOA levels was length of residency in Moose Creek. ATSDR considered residency duration to be a suitable surrogate for drinking water exposures because only residents who lived in the sampling frame before the eligibility date (December 2017) would have had any exposure to the PFAS-contaminated drinking water, and because of the likelihood that exposure would increase with the number of years that EA participants lived in the area. However, because older adults tended to live in the sampling frame longer, this variable was also highly correlated with age. Because of this, it was unclear from univariate models alone whether the association between the time someone lived in the sampling frame and PFAS blood levels was primarily due to age. After controlling for other variables, the multivariate statistical analysis found that residency duration did not remain statistically associated with blood PFAS levels, and age remained statistically associated with blood PFHxS, PFOS, and PFOA levels.
- ATSDR also considered associations with blood PFAS levels and multiple exposure history questions pertaining to drinking water. Notably, these questions pertained to current drinking water practices. It is uncertain whether responses about current drinking water sources would have applied to past drinking water practices. In multivariate models, 1) drinking water consumption rates were statistically associated with blood PFHxS and PFOA levels; 2) participants who reported drinking primarily bottled water had lower blood PFHxS and PFOS levels than those who reported primarily drinking private well water (which would generally have been treated with a GAC filtration system); and 3) participants who reported drinking primarily from a public water system (which includes those receiving delivered water) had lower blood PFHxS and PFOS levels than those who reported drinking primarily private well water. In ATSDR's univariate analyses, participants who reported using a filter or treatment device on tap water at home had on average higher PFOS blood levels. Although the direction of this result is the opposite of what was expected, after controlling for other variables in multivariate analyses, this relationship was no longer significant. ATSDR believes the initial unexpected association for PFOS was because the Air Force installed treatment devices, particularly whole house filters, on private wells that exceeded EPA's HA or AK DEC's Action Level. In other words, participants who currently have filters installed by the Air Force previously had elevated PFAS levels in their drinking water. No PFAS were detected in the samples collected from households with GAC filtration systems as part of this EA. These results provide further evidence for a drinking water exposure route for PFHxS, PFOS, and PFOA.
- PFHxS, PFOS, and PFOA were highly correlated in blood (r = 0.88) suggesting similar or common background sources or exposure pathways. PFHxS and PFOS, and to a lesser extent PFOA, have many common exposure sources, as these compounds are often found together in consumer products. In addition, a common historical formulation of AFFF contained PFOS and precursors that can break down to PFHxS and PFOA. While correlations between PFAS have been observed

in other studies [NH DPHS 2016; ATSDR 2013; CDC 2019], the correlations observed between these two PFAS in this EA are much higher than those observed in the general U.S. population (*r* between 0.46 and 0.66) [Calafat et al. 2007]. The high correlation between blood PFHxS, PFOS, and PFOA observed in Moose Creek is consistent with that found in the blood of people living in a community with contaminated drinking water [ATSDR 2013], providing further evidence that drinking water was likely a contributing source of exposure among Moose Creek EA participants. In addition, the correlations between PFHxS and PFOS in this study are much higher than the correlations observed for PFNA, and MeFOSAA, providing further evidence of a distinct exposure pathway for these two compounds.

Taken together, the data suggest that past drinking water exposure contributed to the elevated blood levels of PFHxS and PFOS observed in the Moose Creek EA participants.

Other Exposure Characteristics

Other exposure characteristics that showed significant associations with blood levels of one or more PFAS in either univariate or multivariate analyses included the following:

- **Soil Exposure.** PFAS can be present in soil that has been irrigated with contaminated drinking water or contaminated through air deposition. In univariate and multivariate models, adult participants who reported coming in contact with soil more frequently had higher blood PFOS levels than those who reported coming in contact with soil infrequently.
- **Occupational Exposure.** Workers can be exposed to PFAS through job tasks that involve manufacturing or working with PFAS. In both univariate and multivariate models, adult participants who reported at least one occupational exposure in the past 20 years on average had higher blood PFHxS, PFOA, and PFOS levels that those who reported no occupational exposure.

These observations are based on limited data and should be interpreted with caution; they will be re-examined in the report analyzing results across all EA sites.

Moose Creek Community-Wide Findings

Finding 1. Average blood levels of PFHxS and PFOS in the Moose Creek EA site participants are higher than national levels. Averages of other PFAS were not higher than the national level or were detected too infrequently to compare to national levels.

Geometric means (i.e., averages) for PFHxS and PFOS blood levels were statistically higher ($p<0.05$) in Moose Creek participants when compared to CDC's NHANES (2015–2016) testing, which was limited to people over 12 years old. The statistically higher blood PFAS levels were observed for both unadjusted geometric means for all EA participants and geometric means adjusted to the age distribution of the U.S. population from NHANES 2015–2016.

Of the PFAS analyzed in blood, PFHxS had the largest elevations when compared to national levels. The age-adjusted geometric mean blood PFHxS level among all Moose Creek EA participants was 7.7 times the national level. Blood PFHxS levels were above the national geometric mean for 96% of the Moose Creek EA participants and above the NHANES 95th percentile for 73% of the participants. The age-adjusted geometric mean blood PFOS level was 3.1 times the national level. Blood PFOS levels were above the national geometric mean for 86% of the Moose Creek EA participants and above the NHANES 95th percentile for 50% of the participants.

Other PFAS measured in this EA (PFOA and PFNA) were not higher than national levels. ATSDR was unable to compare the geometric mean MeFOSAA levels because MeFOSAA was detected in less than 60% of NHANES samples. PFUnA and PFDA were detected in fewer than 60% of the EA participant samples; due to the large percentage of samples below the limit of detection, geometric means were not calculated.

Finding 2. Elevated blood levels of PFHxS and PFOS may be associated with past drinking water contamination.

PFOS and PFOA were detected in Moose Creek private wells as early as 2015, though contamination likely began earlier. The Air Force did not provide ATSDR measurements of PFHxS in private drinking water wells. However, measurements taken from unfiltered water samples in this EA indicate that PFHxS is present in groundwater in Moose Creek. PFOS had statistically elevated blood levels compared to national geometric means. The maximum concentrations measured by the Air Force in private drinking water wells in Moose Creek were 3,100 ppt for PFOS and 250 ppt for PFOA (note the maximum PFOA concentration measured in EA participant drinking water wells was 153 ppt).

Between 2015 and 2017, actions taken by the Air Force reduced PFAS levels in drinking water in the affected area below the EPA HA for PFOS and PFOA and AK DEC Action Levels for multiple PFAS. Before 2016, PFAS-containing AFFF were primarily formulated with PFOS, but also contained various PFAS precursors that could break down into other PFAS, such as PFHxS, which could explain the elevated blood PFHxS levels. PFHxS, PFOS, and PFOA have long biological half-lives (on the order of years). There were 2 years and 8 months between when the Air Force provided alternative water to reduce exposure to contaminated drinking water and collection of biological samples during the EA. Because of the long half-lives of PFHxS, PFOS, and PFOA, past drinking water exposures may have contributed to the EA participants' blood levels. PFHxS has the longest estimated half-life of the three compounds (4.7 to 35 years), which may contribute to why it exceeded the NHANES 2015-2016 geometric mean by the largest margin.

PFHxS and PFOS were highly correlated in Moose Creek residents' blood (Pearson correlation coefficient, $r = 0.88$). This means that, typically, residents who had elevated blood PFHxS levels also had elevated blood PFOS levels. This correlation suggests a common exposure source, such as the drinking water, though other sources of exposure may also have contributed to the observed blood levels. Additional observations from the multivariate analyses support the finding that past exposure to contaminated drinking water contributed to the elevated blood levels.

- First, adults who reported mainly drinking bottled water at home on average had statistically lower PFHxS (57%) and PFOS (64%) blood levels when compared to those who reported mainly drinking private well water.
- Second, adults who reported drinking primarily from a public water system (which included water delivered by the Air Force) had statistically lower PFOS (56%) blood levels than those who reported drinking primarily private well water.
- Third, for each additional cup of water drank at home per day, blood PFHxS levels increased by 2.3%.

Finding 3. Age, sex, soil exposure, occupational exposure, breastfeeding, and childbirth were associated with some PFAS blood levels.

PFAS blood levels varied with different demographic and exposure characteristics of the participant population. The following relationships were statistically significant in multivariate analyses in the

Moose Creek EA data set in adult participants (and are consistent with those reported in other non-ATSDR PFAS studies):

- Blood levels of PFHxS, PFOS, and PFOA were higher in older participants, and the size of the effect varied by sex for PFHxS and PFOS.
- Males had statistically higher blood levels of PFHxS and PFOS than females. The difference between males and females was larger in younger people. For example, 30-year-old males had higher blood PFHxS and PFOS levels than 30-year-old females by 196% and 272%, respectively. For 50-year-old participants, these differences were reduced to 88% for PFHxS and 95% for PFOS, respectively.
- Participants who reported coming in contact with soil three times a week or more had 92% higher blood PFOS levels than those who reported coming in contact with soil a few times per years or less.
- Adult participants who reported at least one occupational exposure in the past 20 years on average had higher PFHxS (239%), PFOS (96%), and PFOA (63%) than adult participants who reported no occupational exposures in the past 20 years.
- Females who breastfed had lower blood levels of PFOS than females who did not. Among female participants, for every one-month increase in breastfeeding duration, blood PFOS levels on average decreased by 1.5%.

Detailed analyses were not conducted for children because fewer than 10 children participated in this EA. The final report on all EA sites will include a more robust analysis of children.

Finding 4. No PFAS were detected in urine.

ATSDR analyzed 9 (10%) of the urine samples collected. No PFAS were detected in any of the samples; therefore, no geometric means were calculated. ATSDR did not analyze all participants' urine samples because none of the species were detected in more than 60% of the samples analyzed.

Finding 5. All Moose Creek drinking water samples collected during the EA in 2020 met the EPA's HA and the Alaska Department of Environmental Conservation (AK DEC) Action Levels for specific PFAS in drinking water.

This is based on 11 filtered and 8 unfiltered samples collected in 13 households during the EA. One of the unfiltered household samples exceeded the EPA HA level and AK DEC Action Level for PFOS; however, this sample was untreated private well water collected at an outdoor spigot that was not used for drinking water. ATSDR also collected water from an unfiltered, unused tap in the sampling frame and found that the PFOS concentration exceeded the EPA HA level and AK DEC Action Level.

Finding 6. Patterns and levels of dust contamination measured in participating EA households are comparable to those reported in selected U.S. studies.

Among the PFAS detected most frequently in household dust samples, N-MeFOSE and FtS 6:2 were measured at the highest concentrations. No nationally representative comparison values are available, but geometric mean and median concentrations for PFAS measured in dust collected in the small subset of participating households (n=13) were within the range of levels reported in a few published studies of other U.S. communities (with or without PFAS contamination). Of the PFAS measured in this EA's household dust samples, PFOS and MeFOSAA were statistically correlated with the same PFAS measured in participants' blood. The final report on all EA sites will include a more robust comparison of PFAS measured in dust and blood.

Limitations

There are several limitations associated with this assessment.

- The EA participant sample may not be representative of the community. All households in the study area were invited to participate, and 15% of the households participated in the EA. Participant characteristics were different than those of the area's overall population, specifically participants were older. ATSDR addressed some of these differences by calculating geometric mean estimates that were adjusted to the age distribution of the community.
- The significant associations reported here between blood PFAS levels and certain demographic and exposure characteristics should be interpreted with caution as they are sometimes based on a limited number of participants.
- Measurement of blood, urine, and environmental PFAS concentrations in EA participants may improve the understanding of exposure in this community but will not provide information about all sources of exposure. Additionally, identifying every potential confounding exposure is not possible.
- While multivariate regression models explained a large portion of the variability in participants' blood PFAS levels (R-squared or R^2, a measure of model goodness-of-fit, ranged between 0.48 and 0.67 in all-adult models), other factors not identified could still influence the relationships reported in this assessment (see "Statistical Analysis" section for details).
- A small number of households in the sampling frame refused testing for PFAS in private wells offered by the Air Force. Because of this, ATSDR is unable to definitively conclude that all drinking water exposures in the area have been mitigated; however, all known drinking water exposures have been mitigated and the Air Force has continued to take action to mitigate exposures when new data become available.
- This EA did not directly assess tap water consumption prior to the mitigation or reduction of PFAS in drinking water from private wells.
- This EA was not designed to investigate health outcomes. Without additional information about exposure-response relationships, the results of this EA cannot be used to assess current or past health problems or predict the future occurrence of disease. PFAS found in a person's blood or urine means that exposure has occurred. The presence of PFAS in blood or urine does not tell us how, where, when, or for how long a person was exposed to PFAS. Exposure to PFAS does not mean adverse health effects will result, either now or in the future.
- The dust results are exploratory and should be interpreted with caution. They are based on a limited set of samples, and in some cases those samples are based on a small sample amount.

Recommendations

This PFAS EA provides evidence that past exposures to PFAS in drinking water have impacted the levels of PFAS in people's bodies. These PFAS are eliminated from the body over a long period of time. This allowed ATSDR to measure PFAS even though exposures through drinking water were mitigated, or lowered, years ago.

Although the exposure contribution from PFAS in private well water in Moose Creek has been mitigated, there are actions community members and other stakeholders can take to further reduce exposures to PFAS and protect public health.

Based on the PFAS drinking water test results from private wells tested by the Air Force in Moose Creek, ATSDR recommends that residents continue to use the alternative sources of water provided by the Air Force at this time.

1. What the Air Force can/should do:
    a. With permission from homeowners, test private wells in the affected area that have not been previously tested.
    b. Continue to monitor and maintain alternative drinking water systems to ensure that the water provided continues to meet all federal and state drinking water guidelines for PFAS.
2. What community members can/should do:
    a. The Air Force has taken action to reduce levels of PFAS in drinking water at homes near Eielson Air Force Base. Based on the information available to ATSDR, the alternative drinking water provided by the Air Force (whether through filters, bottled water, or tanks) currently meets all federal and state guidelines for PFAS. ATSDR recommends that community members continue to use these alternative water sources. The long-term solution is to connect your home to piped water from a source that meets all federal and state drinking water guidelines for PFAS.
    b. Residents should coordinate monitoring and maintenance of the water filtration systems with the Air Force until such time as piped water is supplied.
    c. Nursing mothers should continue breastfeeding. Based on current science, the known benefits of breastfeeding outweigh the potential risks for infants exposed to PFAS in breast milk.
    d. When possible, eliminate or decrease potential exposure to PFAS in consumer products such as stain-resistant products and food packaging materials. To learn more visit: https://www.fda.gov/food/chemical-contaminants-food/questions-and-answers-pfas-food.
    e. Pay attention to advisories about food consumption, such as local fish advisories. Because of PFAS in lakes and creeks near Eielson Air Force Base, Alaska Department of Fish and Game currently allows only catch and release sport fishing in Polaris Lake, Bear Lake, Moose Lake, Bathing Beauty Pond, Piledriver Slough, and Moose Creek.
    f. Discuss any health concerns or symptoms with your health care provider. Share results of PFAS blood testing with your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html). Follow the advice of your health care provider and the recommendations for checkups, vaccinations, prenatal care, and health screening tests.
    g. At this time, ATSDR does not have plans to conduct additional blood testing for PFAS or recommend PFAS EA participants get individually retested for PFAS in blood. The biological half-lives of many of the PFAS measured in people's blood are long. PFHxS, in particular, has one of the longest half-lives—some estimates range in the decades. This means that PFAS blood levels are not expected to change significantly in the near-term, even if exposure stops. Additionally, it is unclear what an individual's PFAS test results mean in terms of possible health effects

       For the general population, blood tests for PFAS are most useful when they are part of a scientific investigation like this EA. Test results will tell you how much of each PFAS is in your blood, but it is unclear what the results mean in terms of possible health effects. In addition, blood testing for PFAS is not a routine test offered by most doctors or health departments.

Talk to your health care provider and make them aware of ATSDR resources for clinicians (https://www.atsdr.cdc.gov/pfas/resources/info-for-health-professionals.html).

h. Follow the advice of your child's health care provider and the recommendations for well child checkups, vaccinations, and recommended health screening tests. Consult https://health.gov/myhealthfinder to help identify those vaccinations and tests.

i. For additional information about environmental exposures and children's health, contact the Pediatric Environmental Health Specialty Units, a nationwide network of experts in reproductive and children's environmental health (https://www.pehsu.net/).

For More Information

If you have questions or comments or want more information on the Moose Creek EA site, call 800-CDC-INFO or email pfas@cdc.gov. For more information on the work CDC/ATSDR is doing to address PFAS exposure, visit ATSDR's PFAS website: https://www.atsdr.cdc.gov/pfas/. For other EA or PFAS-related questions, email pfas@cdc.gov.

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This list includes references for Appendices A, B, and C, as well as the sections above.

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